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FEASIBILITY STUDY OF A 400 HZ, 4160 VOLT  
3-PHASE ELECTRICAL POWER DISTRIBUTION SYSTEM

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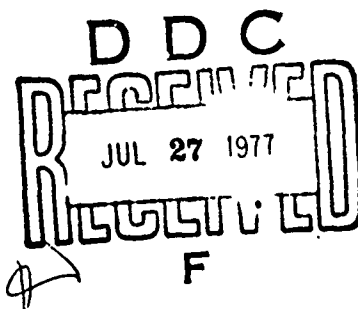
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## SECTION 1

### GENERAL

#### 1.1 INTRODUCTION.

The purpose of this study is to establish the technical and economic feasibility of generating 400 Hz power at a central location and distributing this power to aircraft operation, maintenance and training facilities at Naval Air Stations (NAS).

At the present time, the 400 Hz power is obtained by use of individual fixed or mobile units located throughout the Naval Air Stations. It is proposed to replace the numerous individual units with a central system consisting of two or more 60/400 Hz generators operating in parallel. Due to the long distances between the central location and the various hangars which require 400 Hz power, it is impractical to distribute the power below 600 volts. This study has concentrated on distribution of the 400 Hz power at 4160 volts. It is this particular application of 400 Hz power at 4160 volts that has not been achieved until now except for an experimental installation at Patuxent River NATC, Maryland (Reference Number 1) which has been operating satisfactorily since November 1975.

#### 1.2 TECHNICAL FEASIBILITY.

The investigations concerning the technical feasibility of the system under study clearly establish that it is quite possible to replace the existing system with a new centralized system of equal or even superior technical capability. It must be pointed out, however, that since a given central 400 Hz system would be servicing an entire NAS, its continuous operation is far more critical than that of any individual unit under the present system. Hence, only the very best and most reliable components should be used in the entire centralized system. In addition, special consideration should be given to the design, execution, installation, testing and maintenance of the system.

#### 1.3 ECONOMIC FEASIBILITY.

The investigations concerning the economic feasibility of the system under study establish that it is possible to replace the existing 400 Hz system with a new centralized system of equal technical capability at an economic advantage. The payback period will vary at each NAS depending

upon many factors such as the quantity of individual units to be replaced by the central system, availability of existing spare underground duct or overhead lines, energy costs, specific construction problems such as distance between hangars, etc. The scope of work statement which describes the work under this study calls for the quality of power of the central system to be such as to comply with the requirements of MIL-STD-704B. Section 2 covers the technological requirements for meeting MIL-STD-704B, while Section 3 covers the economic feasibility aspects.

#### 1.4 NATURE OF THE 400 HZ LOAD.

##### 1.4.1 Categories.

There are five major categories of 400 Hz loads:

- a. HANGARS - Aircraft training, maintenance and testing.
- b. PARKING RAMPS (APRONS) - Aircraft testing prior to takeoff.
- c. AVIONICS SHOPS - Servicing of electronic equipment.
- d. TRAINING FACILITIES
- e. SPECIAL REQUIREMENTS - Tacamo (Pax River NATC), Radar Test Cells (Oceana NAS) (Reference Number 3).

##### 1.4.2 Maximum Demand and Load Diversity.

Results published in Report Number 3-75 entitled "Aircraft Ground Support - Standardization of Shore based Electrical Servicing Systems" dated January 1975 and prepared by ESA-1182 of Naval Weapons Engineering Support Activity, were used to arrive at the various maximum demand and load diversity patterns.

##### a. Maximum Demand in Hangars.

Refer to Appendix G for maximum starting and servicing power requirements for various type aircraft. Also, Report Number 3-73 "Aircraft Ground Support 400 Hz Electrical Power Requirements Evaluation", ESA-742:NWESA dated January 1973, revealed that an aircraft's entire electrical load is never suddenly applied on the ground in practical applications and that the loads are applied in relatively small steps (see reference to this statement in Reference Number 10).

Additional data concerning this topic is covered in Reference Number 11.

b. Load Diversity of Aircraft.

Refer to Appendix H for load diversity curve.

- c. NAS Oceana Report - Project ESR #7-74 (Reference Number 12) indicates 18 percent loading on existing motor generators.
- d. Avionics shop loads consist of VAST loads, maximum of 40 amperes each. This load is constant. (See report from visit to NAS Oceana, Virginia - Reference Number 6.)

1.4.3

Conclusions.

The data referenced in Paragraph 1.4.2 cover all of the available information concerning maximum demand load and load diversity patterns at Naval Air Stations. While the available information is very extensive, it is not conclusive when the area of interest is extended from a portion of the total load to all of the loads which may occur simultaneously at an entire Naval Air Station.

In addition to the data which is available on the fixed installation, consideration should be given to the use of the mobile equipment. In the absence of more specific existing data, this study is based on an estimate that approximately five percent of the available mobile equipment must be added to the maximum demand load of the fixed equipment.

Using NAS Miramar as an example, and with the above assumptions, the capacity of the proposed centralized 400 Hz system is as follows:

$$\begin{array}{rcl} 575 \text{ KVA} & = & 15\% \text{ of } 3,830 \text{ KVA connected capacity of fixed equipment} \\ + \text{ } 325 \text{ KVA} & = & 5\% \text{ of } 6,480 \text{ KVA total capacity of mobile equipment} \\ \hline 900 \text{ KVA} & = & \text{Total capacity of 400 Hz centralized system} \end{array}$$

It should be noted that the mobile equipment is used for two purposes: where the 400 Hz distribution is inadequate and as back-up for any fixed unit which has failed. Hence, in those stations where the existing 400 Hz distribution is poor, the requirement for mobile units is high. A review of Appendix D indicates that on nine NAS' under study, the ratio of fixed to mobile units in terms of total available KVA ranges from 8.1 percent to 80 percent; the average is approximately 40 percent. Analysis of a specific NAS should take into

account the actual ratios of fixed to mobile equipment when calculating the capacity of the centralized 400 Hz system. Different weighing factors must be assigned to mobile power capacity and fixed power capacity, in accordance with the preceding specific example.

#### 1.4.4 Voltage.

Utilization voltage is 115/200V, 3-phase, 4-wire.  
Distribution voltage is 4160 VAC, 3-phase.

In computing voltage drop, a maximum length of 16,000 feet has been used as this is the largest run encountered. This maximum length occurs at Patuxent River NATC, Maryland. It is not practical to distribute precise 400 Hz power at length in excess of 16,000 feet. Because of the very tight voltage limits, it is not possible to use the voltage taps on the high voltage transformer to offset losses due to the long runs and thereby possibly exceed the upper limits of the input voltage. From an economic point of view, the 16,000 feet limit would also prove to be the maximum practical length. Hence, should a particular NAS require a run in excess of 16,000 feet, a second central 400 Hz power system should be installed, which would serve the remotest group of load.

### 1.5 400 HZ EQUIPMENT AVAILABILITY.

1.5.1 60/400 Hz equipment such as motor-generator sets and transformers are readily available. Other equipment required for the system such as wire and cable, switchboards, circuit breakers, etc., designed for use at 60 Hz may also be adapted for use at 400 Hz, sometimes with a derating factor. There are no requirements for totally new equipment to be developed specifically for use at 400 Hz.

1.5.2 Various manufacturers were contacted verbally as well as in writing. Letter dated June 18, 1976, is included as Reference Number 8. Some of the manufacturers who were contacted are as follows:

Cyprus Wire and Cable Company  
General Electric Company  
I-T-E Imperial Corporation  
ITT - Royal Electric Division  
ITT - Jennings Division  
Okonite Company  
Square D Company  
Teledyne Crittenden  
Teledyne Inet  
Westinghouse Corporation

The response obtained so far has been limited to Okonite, Cyprus, Teledyne Inet, Teledyne Crittenden, ITT - Royal and ITT - Jennings.

Due to the relatively poor interest exhibited by the various manufacturers, a second letter was generated. This letter is dated August 11, 1976 and is referenced as Reference Number 9. Outline specifications and associated questionnaire for each of four major categories of hardware were included with the letter. The response from those manufacturers has been summarized in Appendix M.

- 1.5.3 Notwithstanding the limited interest exhibited by the various potential suppliers, it is JB & B's conclusion that there is sufficient equipment and knowledge on the application of such equipment at 400 Hz that it is technically feasible to install a successful centralized 400 Hz/4160 volt system.
- 1.5.4 Centralized 400 Hz power systems have been used at many airports in the U. S. A. and throughout the world. However, there is no 400 Hz centralized system distributed at 4160 volts. A 400 Hz system was recently installed at the Arlanda Airport in Stockholm, Sweden. This system consists of four 250 KW/312 KVA running in parallel. Any two units can supply the full load. The control system includes automatic starting, automatic paralleling, and automatic generator shutdown. The 400 Hz output of the motor-generator units is distributed at 1000 volts.

The cost effectiveness of the centralized 400 Hz power generating system has been proven conclusively at commercial airports. It is JB & B's conclusion that the same cost effective measures may be successfully implemented at Naval Air Stations.

#### 1.6 FIELD VISITS.

- 1.6.1 Field visits were made to obtain firsthand knowledge of operational and maintenance requirements at Naval Air Stations. Visits were made to the following:

NAS Oceana, Virginia  
NAS Cecil Field, Florida  
NAS Miramar, California  
NATC Patuxent River, Maryland

- 1.6.2 Details of the site visits are described in Reference Number 6 - Progress Report Number 2.
- 1.6.3 Data requested from the Public Works Office at each of the above sites was submitted in the form of a questionnaire which was mailed prior to the actual visit. This questionnaire is referenced as Reference Number 7.

- 1.6.4 Data obtained from the above visits have been reviewed and a list is included in Reference Number 6.

1.7 RECOMMENDATIONS.

JB & E recommends that the centralized 400 Hz power generation and distribution system at 4160V be implemented as soon as is practical at Naval Air Station facilities for the following reasons:

- a. Economic - The centralized 400 Hz power system has an overwhelming economic advantage over the individual generator units presently used, as indicated in Section 3 of this report.
- b. Technical - The centralized 400 Hz power system offers a higher degree of reliability and availability of 400 Hz power than individual generator units.

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## SECTION 2

### TECHNICAL FEASIBILITY

#### 2.1 INTRODUCTION.

An analysis was conducted as to the feasibility of 400 Hz High Voltage power distribution based on the availability and cost of suitable electrical equipment. The analysis takes into account the essential difference between power distribution problems at 60 Hz and at 400 Hz. In developing a 400 Hz, 4160 VAC power generation and distribution system, not all components in the electrical system represent problems for study. Low voltage (below 600 VAC), 400 Hz power generation and distribution systems are not new, and are in common usage at airports and Naval Air Stations around the world, where the 400 Hz is used to service aircraft.

The components of the system not requiring significant study include the following:

- a. 60 Hz input power bus.
- b. Input power circuit breaker.
- c. Low voltage (less than 600 VAC) circuit breaker (generator output).
- d. Low voltage circuit breaker in low voltage 400 Hz distribution system.
- e. Low voltage 400 Hz power distribution cable.
- f. Load circuit breakers.
- g. Load cable.
- h. Connectors.

The load cable is a 4-wire flexible cable, of either Size No. 6 AWG or No. 2 AWG, depending on the expected load current and on the length of the load cable. The heavier cable provides a lower voltage drop.

The replaceable connector is rated for up to 250 amperes, and tooling exists to accept either four No. 6 AWG wires or four No. 2 AWG wires. The connector is standard for use in the Navy and Air Force, under Part Number MS90328 for complete cable assemblies or Part Number MS25486 for plugs only.

## 2.2 EQUIPMENT STUDY.

The study dwells primarily on:

- a. The motor-generator set in combination with a step-up transformer and harmonic filter to provide 3-phase, 4160 VAC, 400 Hz power.
- b. 4160 VAC, 3-phase distribution system for the 400 Hz power.
- c. Switchgear in the 4160 VAC, 3-phase system at the generation plant.
- d. Utilization transformers which step down the high voltage 400 Hz power to nominal 115/200 VAC for the load in combination with either voltage regulators or line drop compensators. Also included is the high voltage protection on the input to the utilization transformers, and the circuit breaker at the output.
- e. As an alternate to the 60/400 Hz motor generator set, a brief study of 60/400 Hz solid-state frequency changers is included.

## 2.3 EQUIPMENT INFORMATION.

As a means of obtaining information about the electrical equipment required, the electrical equipment were grouped in what is considered to be logical combinations, and specification outlines were developed. The prospective suppliers were provided with the following. (See Appendix L, Appendix M and Reference Number 9).

- a. A letter explaining the problem.
- b. The equipment specification outline.
- c. A questionnaire with request for proposal.

## 2.4 EQUIPMENT GROUPING.

The equipment groups and reasons for the groupings are as follows:

- a. Motor generator and step-up transformers, with all meters, controls, etc.

This combination permits the manufacturer to propose either a motor generator set combined with a step-up power transformer (400 Hz central power station transformer) or a direct 4160 VAC generator. In either case, performance specifications apply to the output at 4160 VAC, and not to the intermediate voltage at 480 volts.

- b. High voltage power distribution cable.

- c. Switchgear at the power generation plant were studied to determine as many suitable options as practical for applications which include automatic, unmanned start-up and switching of motor generator sets in accordance with load demand.
- d. The utilization transformers were combined with the voltage regulators and/or line drop compensators, because of their interdependence.
- e. Input switchgear to the utilization transformer does not need to be more than a fused oil cut-out switch to permit safe service work on the transformer. The output circuit breaker is for transformer overload protection and is, therefore, included as part of this assembly.
- f. EMI filters in a power distribution system were separated out for special study. The conclusion is that filters are not required but shielding of utilization transformers is required to minimize propagation of EMI signals.

Note: Equipment must be derated for service at 400 Hz in accordance with the recommendations of the specific manufacturer. An example of how one particular manufacturer derates his equipment is included in Appendix M - letter from G. E. Company dated October 5, 1976.

## 2.5

### MIL-STD-704B.

#### a. Introduction.

The quality of 400 Hz AC electric power on board U.S. military aircraft is defined by MIL-STD-704B.

MIL-STD-704A is entitled "Electric Power, Aircraft, Characteristics and Utilization of", and has been the controlling document for many years. As a result, most existing electrical utilization equipment, requiring 400 Hz power, has been designed to MIL-STD-704A requirements.

MIL-STD-704B was issued on 18 November 1975 entitled "Aircraft Electric Power Characteristics", and will control electrical utilization equipment designed after November of 1975. Therefore, the quality of 400 Hz AC power provided from a central generating and distribution system, would necessarily have to meet requirements of MIL-STD-704B. For most, but not all requirements, MIL-STD-704B is more strict and hence, if MIL-STD-704B requirements are complied with, MIL-STD-704A requirements are also met.

Table 1, Page 41, lists the limits of 400 Hz AC power for MIL-STD-704B. The objective of the centralized 400 Hz power system design is to meet these requirements.

The problems of compliance with MIL-STD-704B requirements are considered below. Also considered are some proposed means of meeting these requirements.

b. Steady-State Voltage. Refer to Table 1, Page 41, Item Number 1.

MIL-STD-704B, Paragraph 5.1.1.1, requires the voltage to be maintained at 108 to 118 VAC at the point of utilization. The point of utilization is the actual electronic load on board the aircraft. The power distribution system can be designed to control voltage drops only to the point of connection to the aircraft. Therefore, a voltage drop allowance must be provided for transmission of 400 Hz power from the point of connection at the skin of the aircraft to the point of utilization on board the aircraft. It has been past practice to allow 4.0 VAC per phase for this voltage drop, as specified in MIL-STD-704A. Therefore, this same voltage drop allowance will be continued. Thus, the allowable range of voltage at the load plug which connects 400 Hz AC power to the aircraft will be set at 112 to 118 VAC.

A motor generator set, or an engine generator set, such as presently used to supply 400 Hz AC power to aircraft, typically are specified to provide voltage regulation of plus or minus 1.0 percent. It is common practice to specify "Remote Voltage Sensing" or "Automatic Line Drop Compensation" in the procurement specifications for 400 Hz generator sets.

If this same standard voltage regulation range were applied to a central 400 Hz power generator, the center value of voltage at the load would be 116.8 VAC and the range would be 115.6 to 118.0 VAC. Since the minimum voltage permitted is 112.0 VAC, this voltage range would provide  $115.6 - 112.0 = 3.6$  VAC allowance for all voltage drops throughout the distribution system. This range is too restrictive. Therefore, the central generators will be required to maintain a voltage tolerance of plus or minus 0.5 percent for all steady state conditions of balanced load, temperature, long time drift and any other factors which can affect the voltage output. The center value of voltage at the load is then 117.4 VAC. The voltage range of the generator output, as referred to the load, will then be 116.8 to 118.0 VAC. The allowance for all voltage drops throughout the system will then be  $116.8 - 112.0 = 4.8$  VAC. This allowance for voltage drops is practical to achieve.

## 2.6

### VOLTAGE REGULATORS.

Electronic type line voltage regulators are expensive and have a level of complexity comparable to that of a motor generator set. Hence, voltage regulators represent a continuing cost in terms of maintenance and servicing. They further represent some significant downtime due to failure occurrence. However, situations may arise in which line voltage regulators will be necessary to achieve a satisfactory voltage range for some specific loads. Only electronic type (non-mechanical brush) regulators have the speed of response required in MIL-STD-704B. Use of electronic regulators in a system or portion of a system will be authorized only when the characteristics of the load warrants such regulators and the additional cost is justified.

In general, use of reactive "Line Drop Compensators" (LDCs) will permit achievement of the required minimal voltage drops in the distribution system. These are passive circuits, low in cost and highly reliable in operation.

## 2.7

### VOLTAGE PHASE UNBALANCE. Refer to Table 1, Page 41, Item Numbers 3 and 4.

Load unbalances and unbalanced impedances in the load distribution cables are the primary two causes of voltage unbalance and voltage phase unbalance. Generators are commonly available in which the phase unbalance for balanced loads is negligible. The load cables which are in widespread use at military bases are not symmetrical. As a result, even under conditions of a balanced aircraft load, substantial voltage unbalance between phases results. Because the power factor of the load and of the power cables are generally very different from each other, there will also be a significant phase angle error between phases when load magnitudes are approaching full rated values.

The problem of maintaining balanced line voltage and of minimizing phase angle errors can largely be corrected where a new central 400 Hz generation and distribution system is installed. Specifications on the major components of the system and on the installation can eliminate the dissymmetry which currently exists in the power cables.

Even under conditions of unbalanced loads, the 400 Hz source impedance of the distribution network and of the central power generators can be maintained sufficiently low to meet the 120 degrees, plus or minus 2 degrees tolerance specified in MIL-STD-704B. However, to meet this requirement, it will be necessary to employ reactive line drop compensators, which will bring the power factor of distribution lines close to unity, and hence, close to the expected impedance of the average aircraft loads.

## 2.8

WAVEFORM. Refer to Table 1, Page 41, Item Number 6.

MIL-STD-704B specification limits the individual harmonic voltage to 2.75 percent. The formula  $V = \pm 0.071 + \sin \theta$ , is equivalent to permitting 7.1 percent deviation factor.

A significant problem is that of supplying a nonlinear load such as one comprised of a three-phase bridge rectifier with an inductor input filter in the DC power. Such a load would be expected as typical in an airborne radar set.

The following are "per unit" considerations. The expected distribution of harmonic current generated in the 400 Hz input power line will be in the neighborhood of the following levels. Only odd harmonics are to be expected, in significant amount.

<u>Harmonic</u>	<u>Current Level (Percent)</u>
3	Zero
5	20
7	14
9	Zero
11	9
13	7.7
15	Zero
17	5.9
19	5.2
21	Zero
23	4.3

These are essentially the harmonic currents in a stepped current waveform which eliminates all even harmonics and all of those which are multiples of three.

Typically the magnitude of the load may represent 15 percent of the generator power rating (a conservative estimate).

A typical generator impedance is 30 percent inductive (typical of aircraft generators) and the distribution line is 2 percent inductive at the fundamental frequency. This totals  $j.32$ . At the 5th harmonic, this will be  $5 \times j.32 = j1.6$ .

The 5th harmonic voltage generated will then be:

$$0.2 \times 0.15 \times j1.6 \times 100 = 4.8 \text{ percent}$$

where, 0.2 is the harmonic current  
 0.15 is the loading factor of the generator  
 $j1.6$  is the impedance of the source at 5th harmonic  
 100 is the factor to obtain percent of harmonic voltage

The 4.8 percent harmonic voltage is substantially out of compliance with the MIL-STD-704B limitation of 2.75 percent for any single harmonic. Further, the limitation on higher frequency harmonics (the 11th and higher) requires a drop-off of 20 DB per decade. It becomes clear that substantial harmonic filtering is required.

The proposed central power generation and distribution system will permit the application of capacitive bypass filters at the various load utilization points whereby the impedance of each power source can be maintained at a low level. Such capacitive filters are inexpensive, small and reliable. Thus, full compliance can be expected with the voltage waveform requirements of MIL-STD-704B.

2.9 AMPLITUDE MODULATION. Refer to Table 1, Page 41, Item Numbers 7 and 8.

MIL-STD-704B limits the RMS voltage to 0.62 VAC. From the standpoint of the central power distribution system design, this limitation is not expected to present a problem.

2.10 FREQUENCY MODULATION. Refer to Table 1, Page 42, Item Numbers 12, 13 and 14.

The 400 Hz central generating plant has large inertia as compared to the typical airborne generator. There is no freedom of motion permitted rotationally between the driving motor and the generator, as is the case for airborne generator. Therefore, no problems are expected with any of the factors relating to frequency modulation for either the existing 400 Hz generators, or the proposed central 400 Hz generator plant.

2.11 VOLTAGE TRANSIENTS. Refer to Table 1, Page 42, Item Number 15.

a. Voltage Surges.

The voltage surge limitations of MIL-STD-704B is considered to represent no problems for a central 400 Hz generator system design. Because capacitive filters at utilization transformers will become a part of the system design (to suppress harmonics generated by the loads), the voltage spike limitation of MIL-STD-704B are expected to be met. Full compliance with MIL-STD-704B can be expected

for this requirement.

b. Long Time Voltage Transients and Interload Effects.

With a large number of individual loads connected in a commonly shared power generation and distribution network, switching one load on or off line will cause voltage transients and voltage steps to be imposed on all of the other connected loads. Refer to Figure 3, Page 50, which illustrates a typical 400 Hz power distribution system such as is being planned for the U.S. Naval Air Stations in this study. The diagram is simplified by omitting all of the switchgear. Impedances listed on the drawing are the fundamental frequency impedances for the various elements of the distribution network, and these are identified as follows.

$Z_g$	Impedance of the parallel set of generators (1 to 6 connected on line).
$Z_{11}$	Transformer impedance (if used) for voltage step-up of 400 Hz power from 575 to 4160 VAC.
$Z_{21}, Z_{22},$ ... , $Z_{2n}$	Impedances of the segments of the 4160 VAC line between branches.
$Z_{31}, Z_{32},$ ... , $Z_{3n}$	Impedances of the utilization transformers for the various loads. These are 4160 to 120/208 VAC.
$Z_{41}, Z_{42},$ ... , $Z_{4n}$	Impedances of low voltage lines which distribute 400 Hz power to load centers. These are 115/200 VAC power lines.
$Z_{51A}, Z_{51B},$ $Z_{51C}, Z_{52},$ $Z_{nA}, Z_{nB},$ $Z_{nC}$	Impedances of the load cables which carry 400 Hz to the aircraft power receptacle.

2.12 GENERATOR RESPONSE TO VOLTAGE TRANSIENTS.

The only nonpassive element in the 400 Hz generator and power distribution network is the generator. Thus, all voltage transients experienced on the system, with a time duration of greater than one-half cycle, will be due to the response of the generator and regulator to load steps.

The response of a typical generator tends to be linear with magnitude of load step. Thus, doubling the load step will cause doubling of the magnitude of

the voltage transient. Based on this, a formula may be written.

$$\Delta V = K \times \frac{\text{Load Step Magnitude}}{\text{Generator KVA Rating}}$$

where  $\Delta V$  is the voltage transient magnitude in percent of output voltage.

K is a constant of the generator and represents the percent voltage transient of the generator response at a 100 percent load step. The generators specified for this equipment are planned to have a rating of 312 KVA at 0.8PF minimum. The K factor will be specified and tests will be called out at load steps of 25 percent and 50 percent to confirm the value of K. K will be 20 percent, or a 0.2 factor.

A minimum of two generators will be used for all normal system operation.

Thus, a 75 KVA, 0.8PF load step will cause a voltage transient to all on line equipment which will be:

$$\Delta V = 20\% \times \frac{75 \text{ KVA}}{312 \text{ KVA}} = 2.4 \text{ percent}$$

Thus, the maximum voltage transient to be imposed on any load connected to the 400 Hz bus will be 2.4 percent of operating voltage, when a 75 KVA, 0.8PF load is switched on and switched off. Voltage transients for lesser magnitude load steps or for loads of higher power factor, will produce proportionately lesser voltage transients. This is so significantly inside of MIL-STD-704B limits, as to not represent any problem to the 400 Hz system.

The recovery time for voltage transients will be specified on the generator to have a maximum time duration of 250 ms after which generator output voltage must be within a specified plus or minus 0.5 percent tolerance band. As a consequence, the maximum transient recovery time on all connected loads will be 250 ms.

Where solid-state frequency changers are used as the source of 400 Hz power, the voltage transients will be limited to less than 15 percent for a 100 percent load step, and time duration will be less than 5 milliseconds (less than 2 cycles).

A minimum of two 312 KVA solid-state frequency changers will be required on-line at all times. The formula is then:

$$\Delta V = K \times \frac{\text{Load Step}}{\text{Frequency Changer Rating}}$$

$$\Delta V = 15\% \times \frac{75}{625} = 1.8 \text{ percent}$$

Recovery time will be less than 5 ms. Thus with a solid-state power source, long time voltage transients will be nearly eliminated.

## 2.13 CONCLUSIONS OF ANALYSIS OF MIL-STD-704B.

Full compliance with all requirements of MIL-STD-704B can be provided in a centralized power generation and distribution system.

JB & B has analyzed the currently used system of 400 Hz power generation and distribution which utilizes individual motor generator sets or engine generator sets. It is JB & B's conclusion that this currently used system complies with the range of 112 to 118 VAC. Thus, if the central 400 Hz power generation and distribution system met this same 112 to 118 VAC range, the quality of power from the new system would be approximately equal to the quality of power in the existing system from the standpoint of steady-state voltage. Data in this study is offered in such a manner that:

- a. Without use of active electronic type voltage regulators in the system, the voltage regulation is 112 to 118 VAC.
- b. By addition of active electronic voltage regulators at utilization transformers, the voltage regulation can be maintained to closer limits, or alternately, the voltage range of 112 to 118 VAC can be maintained with the application of very large 400 Hz loads. Thus, the active voltage regulators are expected to be required if specified and when authorized for special applications.

## 2.14 DESCRIPTION OF 400 HZ CENTRAL POWER GENERATION AND DISTRIBUTION SYSTEM.

Refer to Figure 1, Page 48 and Figure 2, Page 49.

The 400 Hz power generating plant is illustrated by the one-line diagram of Figure 1, Page 48. 60 Hz input power for the generators will be derived from a high voltage line of suitable capacity. The primary 60 Hz bus would probably be in the 4.16KV to 15KV range. As illustrated, a redundant set of 60 Hz stepdown power transformers is provided. These might be in the power capacity range of from 500 to 1500 KVA, as related to the actual load on a base. One more motor generator unit would be provided than required

to support the maximum expected load. Generator output rating recommended is 312 KVA, 250 KW at 575 VAC, or 480 VAC, as required, 3-phase, 400 Hz. The drive motor recommended would be a synchronous 400 HP, 3-phase, 480 volt, or 575 volt.

The motor and generator combination are direct coupled, and are to be of the highest practical reliability. The generators are parallelable under load, with minimal voltage transients regardless of load, within the rating of the system. The illustrated system could supply up to 937 KVA, 750 KW of 400 Hz power from any three of the four generators. As illustrated, central power station 400 Hz transformers would be 1000 KVA each and would provide a nominal secondary AC voltage of 4160 VAC. Either one of the two 400 Hz transformers may be isolated and the remaining transformer can provide power to any of the 400 Hz, 4160 VAC feeders. Circuit breakers provide protection to the entire generator plant.

The generator-transformer combination will provide nominal 4160 VAC, regulated to a set point within plus or minus 0.5 percent for balanced loads, and to within plus or minus 1 percent for loads unbalanced to 5 percent between line-to-line loads. Output from the 400 Hz central power station transformers will be 4-wire wye, with the neutral grounded through a capacitor or resistor to limit short circuit current. Lightning arresters will be required on the incoming 60 Hz power bus and on the 4160 VAC, 400 Hz output bus.

A meter and control panel are part of each individual 400 Hz generator set. Protective relays are included whereby a fault in any one generator causes automatic disconnection of the faulted unit.

The generator plant specifications will include a requirement for EMI suppression to meet MIL-STD-461, Class V requirements. This is the same requirement imposed on all new military 400 Hz mobile electric power plants.

In Figure 1, Page 48, a typical 400 Hz distribution line is illustrated. In Figure 2, Page 49, one of these lines is illustrated in more detail. Two load branches are illustrated in Figure 2, Page 49. One branch is illustrated near the generator plant and the lower branch is illustrated as requiring some substantial length of 4160 VAC distribution bus. One branch is illustrated as requiring an active voltage regulator at one load.

The upper branch includes:

- a. Circuit breaker.
- b. Line drop compensator for reactive power line drop.

- c. Stepdown utilization transformer from 4160 VAC to nominal 117.4/203.3 VAC, 400 Hz
- d. Shunt capacitive harmonic filter
- e. 115/200 VAC distribution cable
- f. Circuit breakers at load centers
- g. Load bus of flexible and neoprene jacketed wire
- h. Anderson plug for aircraft connection

The lower branch includes all of the above plus Item i.:

- i. Three single-phase electronic fast response, low harmonic voltage regulators with one provided for each phase of the load

The survey of power requirements indicates that most individual aircraft will present loads of substantially less than 30 KVA. Therefore, each load bus will be protected by a 225 amp frame circuit breaker with overload trips set to 100 amps and provided with a shunt trip. The breaker will be in a wall-mounted cabinet with a light to show "Power On" and a second light to show "Power Available".

The stepdown utilization transformers proposed are rated at 75 KVA. Up to twelve low voltage loads can be connected to a single power transformer, each load individually rated at up to 37 KVA. The expected demand factor of the loads, for most installations, is expected to be 15 percent. Thus, the average load is not expected to exceed 15 percent of 37 KVA or 5.5 KVA at each of the twelve loads.

The distance of the circuit breaker connections from the transformer must be of limited distance, typically 75 feet, in order to limit voltage drops. Thus, all of the proposed twelve load centers must be within these distances. Where longer power runs are required, they can be accommodated by use of dual low voltage power cables.

Calculations are now made for voltages at:

- (A) Two 37 KVA loads at a location which is 5,000 feet from the central 400 Hz generating plant and which are both near the end of the proposed 75 feet low voltage distribution cable.
- (B) Same as above, but the loads are now 16,000 feet from the central 400 Hz generating plant.
- (C) Eight loads of 37 KVA each are distributed at 2,000 feet intervals along the high voltage distribution cable. Total of these eight loads is 296 KVA.

For calculations which follow, "Conditions (A), (B) or (C)" will meet the above. For each of these load conditions, the objective is to meet MIL-STD-704B requirements, with an allowance of 4.0 VAC voltage drop on board the aircraft. Thus, the range is 112 to 118 VAC.

Loads will be assumed to be (1) resistive, and (2) 0.8 power factor.

## 2.15 VOLTAGE DROP CALCULATIONS.

Electrical characteristics of the power distribution system are:

- a. One of the standard transformer voltage ratios in common usage is the 4160 to 120/208 VAC ratio which represents an exact 20:1 ratio. Since this voltage ratio is suitable to this application, it will be adopted for the utilization transformers. Actual operation will be at a slightly lower level to accommodate the 118/204 VAC actual maximum open circuit voltage required by MIL-STD-704B. Taking account of the plus or minus one-half percent tolerance of the central 400 Hz generators and the consequent 117.4 VAC nominal open circuit voltage at the load, a nominal 4067 VAC, plus or minus one-half percent, open circuit voltage on high voltage distribution system is required. Based on the above, the utilization transformers will have an exact primary to secondary voltage ratio of 20. Therefore, the voltage transformation factor will be 0.05 and impedance ratios will be  $(0.05)^2 = 0.0025$ . Output voltage will be 117.4 VAC, plus or minus 0.5 percent, and the output voltage range will be 116.8 to 118 VAC.
- b. Voltage at the 400 Hz generation plant will be maintained at 4067 VAC, plus or minus one-half percent. This value of high line voltage was selected to establish the values in Item a. above.
- c. The high voltage distribution cable (HV Line) is triplexed 3/C Number 1/0 shielded wire having a calculated impedance of  $0.12 + 0.22j$  per 1,000 feet at 400 Hz and 40° C average temperature.

$$Z(HV) = (0.12 + 0.22j) \text{ per 1,000 feet}$$

- d. The low voltage power distribution cable (LV Line) connects the output of the utilization transformers to circuit breakers at the load centers. The LV Line is 3/C Number 4/0 phase conductors plus 3/C Number 4 insulated neutral triplexed and armored with aluminum. The calculated impedance is  $0.078 + 0.18j$  per 1,000 feet at 400 Hz and 40° C. The average length of the LV Line is estimated to be 75 feet and will have an impedance:

$$Z(LV) = 0.005 + 0.014j$$

- e. The load distribution power cable (Load Cable) is four conductor No. 2 AWG twisted cable, 50 feet long, per MIL-C-3432D terminated in an Anderson Plug Type R67G18A. The Load Cable connects 400 Hz power from the wall-mounted circuit breaker to the aircraft. Impedance is  $0.18 + 0.22j$  per 1,000 feet for the 50 foot length at 400 Hz.

$$Z(LO) = 0.007 + 0.009j$$

- f. The 75 KVA utilization transformers will be equipped with a reactive line drop compensation circuit. The transformer and line drop compensation circuit will have an output impedance of approximately:

$$Z(TR) = 0.005 - 0.023j$$

- g. The transformers to be used at the 400 Hz power generation plant will have the resistive and reactive components of impedance cancelled by the generator load compensation circuit and will provide an essentially zero impedance source for steady state operation.

- h. Reactances of cables were computed using the formula:

$$X_i = 2\pi f \left( 0.1404 \log \frac{2D}{d} + 0.0153 \frac{L}{L_o} \right) \times 10^{-3}$$

where  $X_i$  = reactive impedance in ohms

$f$  = frequency in Hz

$D$  = distance between two conductor centers in inches

$d$  = diameter of conductor in inches

$\frac{L}{L_o}$  = correction factor from Table 1, Appendix J

The reactances are line-to-neutral.

## 2.16 METHOD OF VOLTAGE DROP CALCULATIONS.

To simplify calculations for voltage drop in power lines when a reactive load is present, the following method is used.

Assume 35 KVA load is applied to a power source at 115/200 VAC and assume a source impedance of  $Z = R + jX_L = 0.02 + 0.05j$ .

The voltage present at the load will be approximately:

$$E_L = E_{OC} - I[R \times PF + X_L \times \sqrt{1 - PF^2}] \text{ or for a 100 amp, 0.8PF load and a power source of 120 VAC open circuit voltage.}$$

$$\begin{aligned} E_L &= 120 - 100(0.8R + 0.6X_L) \\ &= 120 - 100(0.02 \times 0.8 + 0.05 \times 0.6) \\ &= 120 - 100(0.016 + 0.03) \\ &= 120 - 4.6 = 115.4 \text{ VAC} \end{aligned}$$

This will be accurate if voltage drops are relatively small as compared to the source voltage.

Example: Complete calculation provides  $I = 80 - 60j$  and the following applies:

$$\begin{aligned} E &= 120 - [(80 - 60j)(0.02 + 0.05j)] \\ &= 120 - [(1.6 + 0.3) - 1.2j + 4j] \\ &= 120 - 4.6 - 2.8j \\ &= \sqrt{(115.4)^2 - (2.8)^2} \\ &= 115.367 \end{aligned}$$

an error of 0.028 percent results from ignoring the  $j$  terms.

## 2.17 CALCULATION OF VOLTAGE DROPS.

The load for Condition (A), refer to Page 21, is two 100 amp loads located 75 feet from the 75 KVA utilization transformer.

- a. For a resistive load, the voltage drop in the load line is:

$$0.007 \times 100 = 0.7 \text{ VAC}$$

- b. The resistive voltage drop in the low voltage line is:

$$0.005 \times 200 = 1.0 \text{ VAC}$$

- c. The voltage drop in the transformer is:

$$0.005 \times 200 = 1.0 \text{ VAC}$$

- d. The voltage drop in the high voltage cable as related to the low voltage level will be:

$$0.12 \times 5 \times 0.0025 \times 200 = 0.3 \text{ VAC}$$

The sum of the voltage drops of a., b., c., and d. is now:

$$0.7 + 1.0 + 1.0 + 0.3 = 3.0 \text{ VAC}$$

Load voltage will now be a minimum of:

$$116.8 - 3.0 = 113.8$$

$$\text{and a maximum of: } 118.0 - 3.0 = 115.0$$

This meets MIL-STD-704B.

Now assume the same load but at 16,000 feet distance as in Condition (B), refer to Page 21. Only Item d. changes from the above to:

$$0.12 \times 16 \times 0.0025 \times 200 = 0.96 \text{ VAC}$$

Now the sum of the voltage drops will be:

$$0.7 + 1.0 + 1.0 + 0.96 = 3.66 \text{ VAC}$$

Load voltage will now be a minimum of:

$$116.8 - 3.66 = 113.14 \text{ VAC}$$

and a maximum of:  $118.00 - 3.66 = 114.34 \text{ VAC}$

Again, the voltage range limits of MIL-STD-704B are met.

Assume now the conditions of (C), refer to Page 21, which are a 37 KVA load at each of eight locations on the distribution line:

a. The voltage drop in the load line is:

$$0.007 \times 100 = 0.7 \text{ VAC}$$

b. The voltage drop in the low voltage line is:

$$0.005 \times 100 = 0.5 \text{ VAC}$$

c. The voltage drop in the transformer is:

$$0.005 \times 100 = 0.5 \text{ VAC}$$

d. Voltage drops in the high voltage line are labeled #1 through #8 below, with #1 location being 2,000 feet from the generating plant and #8 being 16,000 feet distance.

$$\#1 = 0.12 \times 2 \times 800 \times 0.0025 = 0.48 \text{ VAC}$$

$$\#2 = \#1 + 0.12 \times 2 \times 700 \times 0.0025 = 0.90 \text{ VAC}$$

$$\#3 = \#2 + 0.12 \times 2 \times 600 \times 0.0025 = 1.26 \text{ VAC}$$

$$\#4 = \#3 + 0.12 \times 2 \times 500 \times 0.0025 = 1.56 \text{ VAC}$$

$$\#5 = \#4 + 0.12 \times 2 \times 400 \times 0.0025 = 1.80 \text{ VAC}$$

$$\#6 = \#5 + 0.12 \times 2 \times 300 \times 0.0025 = 1.98 \text{ VAC}$$

$$\#7 = \#6 + 0.12 \times 2 \times 200 \times 0.0025 = 2.10 \text{ VAC}$$

$$\#8 = \#7 + 0.12 \times 2 \times 100 \times 0.0025 = 2.16 \text{ VAC}$$

At the corresponding load points, the voltage drops at each of the eight locations, due to all losses, will be the sum of a., b., c., and d. which are:

#1	2.18 VAC	#5	3.50 VAC
#2	2.60 VAC	#6	3.68 VAC
#3	2.96 VAC	#7	3.80 VAC
#4	3.26 VAC	#8	3.86 VAC

Corresponding minimum and maximum voltages are:

	<u>Maximum</u>	<u>Minimum</u>
#1	115.80	114.62
#2	115.40	114.20
#3	115.04	113.84
#4	114.74	113.54
#5	114.50	113.30
#6	114.32	113.12
#7	114.20	113.00
#8	114.14	112.94

These voltage ranges meet limits of MIL-STD-704B.

Repeating these same voltage drop calculations except with a 0.8 power factor load, provides the following:

- a. Two 37 KVA loads (200 amps total) located 5,000 feet from the generating plant. The load cable plus the low voltage line, plus the transformer, plus the high voltage line, now have a total impedance of:

$$\text{Low Voltage Line} = 0.005 + 0.014j$$

$$\text{Load Cable} = 0.007 + 0.009j$$

$$\text{Transformer} = 0.005 - 0.023j$$

$$\text{High Voltage Line} = 0.12 \times 5 \times 0.0025 + (0.22 \times 5 \times 0.0025)j$$

$$\text{or } 0.0016 + 0.0027j$$

$$\text{Total is: } 0.0186 + 0.0027j$$

The 0.8 power factor, 200 amp load will cause a voltage drop of:

$$0.0186 \times 200 \times 0.8 + 0.0027 \times 200 \times 0.6 = 3.28 \text{ VAC per phase}$$

The voltage range at the load will be 116.8 - 3.28 minimum and 118.00 - 3.28 maximum or 113.52 to 114.72.

This meets limits of MIL-STD-704B.

- b. Repeating these calculations for the 200 amp, 0.8 power factor load as in a., except at 16,000 feet, the following applies:

Only the high voltage line impedance changes:

$$\begin{aligned} & 0.12 \times 16 \times 0.0025 + (0.22 \times 16 \times 0.0025)j \\ & = 0.005 + 0.009j \end{aligned}$$

Total impedance is now:

$$\begin{aligned} & (0.005 + 0.007 + 0.005 + 0.005) + (0.014 + 0.009 - 0.024 \\ & + 0.009)j \quad \text{or} \quad (0.022 + 0.009j) \end{aligned}$$

The 0.8 power factor, 200 amp load will cause a voltage drop of:

$$0.022 \times 200 \times 0.8 \times 0.009 \times 200 \times 0.6 = 4.6 \text{ VAC}$$

The voltage at the load will now be 112.2 to 113.4 VAC.

This meets limits of MIL-STD-704B.

- c. The voltage drops and resultant voltage at the load are calculated below for 100 amps, 0.8 power factor loads (37 KVA) distributed at 2,000 foot intervals along the high voltage line.

The transformer, load line and low voltage line impedances combined have an impedance of:

$$\begin{aligned} & (0.005 + 0.007 + 0.005) + (0.014 + 0.009 - 0.023)j \\ & = 0.017 + 0.000j \end{aligned}$$

with a 100 amp, 0.8 power factor load, the voltage drop will be:

$$0.017 \times 100 \times 0.8 = 1.36 \text{ volts}$$

A 2,000 feet length of high voltage cable will have an equivalent impedance of:

$$(0.12 \times 2 \times 0.0025) + (0.22 \times 2 \times 0.0025)j$$

$$= 0.0006 + 0.0011j$$

The eight sections of 2,000 feet high voltage cable between load branches will have voltage drops of:

$$0.0006 \times I \times 0.8 + 0.0011 \times I \times 0.6$$

These section voltage drops are then:

$$(0.00048 + 0.00066)I = 0.00114 \times I$$

	<u>Section Drop</u>	<u>Accumulated Voltage Drop</u>
#1 = $800 \times 0.00114 =$	.912 VAC	0.91
#2 = $700 \times 0.00114 =$	0.8 VAC	1.71
#3 = $600 \times 0.00114 =$	0.68 VAC	2.40
#4 = $500 \times 0.00114 =$	0.57 VAC	2.97
#5 = $400 \times 0.00114 =$	0.45 VAC	3.43
#6 = $300 \times 0.00114 =$	0.34 VAC	3.77
#7 = $200 \times 0.00114 =$	0.23 VAC	4.00
#8 = $100 \times 0.00114 =$	.114 VAC	4.11

Total voltage drops and voltage ranges will be:

	<u>Total Drop</u>	<u>Voltage Range</u>
#1 = $1.36 + 0.91 =$	2.27	114.53 - 115.73
#2 = $1.36 + 1.71 =$	3.07	113.73 - 114.93
#3 = $1.36 + 2.40 =$	3.76	113.04 - 114.24
#4 = $1.36 + 2.97 =$	4.33	112.47 - 113.67
#5 = $1.36 + 3.43 =$	4.79	112.01 - 113.21
#6 = $1.36 + 3.77 =$	5.13	111.67 - 112.87

	<u>Total Drop</u>	<u>Voltage Range</u>
#7 = $1.36 + 4.00 =$	5.36	111.44 - 112.64
#8 = $1.36 + 4.11 =$	5.47	111.33 - 112.53

The worst case voltage falls 0.67 volts out of MIL-STD-704B limits. A reduction to 85 amps per load for distributed 0.8 power factor loads brings the voltage within limits. A calculation of only the farthest load is as follows:

$$\text{Fixed drops are: } 0.017 \times 85 \times 0.8 = 1.156 \text{ VAC}$$

$$\text{The line drop is: } 36 \times 85 \times 0.00114 = 3.48 \text{ VAC}$$

$$\text{Total drop is then: } 1.156 + 3.48 = 4.636 \text{ VAC}$$

Voltage range is now at worst point (#8):

$$V = 112.16 \text{ to } 113.36 \text{ VAC}$$

This meets limits of MIL-STD-704B.

If no reactive line drop compensator is included as part of the 75 KVA utilization 400 Hz transformer, the voltage drops are excessive for 0.8 power factor loads.

A transformer impedance without the compensator will be approximately:

$$Z(\text{TR}) = 0.005 + 0.015j$$

The impedance for a 200 amp, 0.8 power factor load will now be:

$$\begin{aligned} Z(\text{Total}) &= (0.005 + 0.014j) + (0.007 + 0.009j) + (0.005 + 0.015j) \\ &= 0.017 + 0.038j \end{aligned}$$

$$\text{Voltage Drop} = 0.022 \times 200 \times 0.8 + 0.066 \times 200 \times 0.6$$

$$V = 2.72 + 4.56 = 7.28 \text{ VAC}$$

Voltage range would be:

$$E = 109.52 \text{ to } 110.72$$

This compares with a drop of 3.4 VAC and  $E = 113.4$  to  $114.6$  VAC with a compensator. This is without considering the voltage drop in the high voltage distribution line.

It is the opinion of JB & B that a system with reactive line drop compensators associated with each utilization transformer, will meet MIL-STD-704B. The only other means available to obtain the acceptable voltage range is through use of oversized transformers and paralleled cable runs. The latter is much more expensive.

## 2.18 DESIGN OF DISTRIBUTION SYSTEM.

This describes the methodology of distribution system design.

The distribution network must limit voltage drops in the 400 Hz power system to meet MIL-STD-704B range of 112 to 118 VAC, which includes a 4.0 VAC allowance for voltage drops on board the aircraft, and including the plus or minus 0.5 percent tolerance of the 400 Hz generators. This restricts the total voltage drop to 4.8 VAC at the 115 VAC level, or to a maximum of  $100 \times (4.8/115) = 4.17$  percent.

Tables and formulas have been developed to aid in designing the distribution system, by taking account of voltage drops in the four component sections, which are:

- a. High Voltage Line (HV Line)
- b. Utilization Transformer
- c. Low Voltage Line (LV Line)
- d. Load Cable

In making estimates, loads are always assumed to be either 1.0 power factor or 0.8 power factor. The military power generation specifications for engine generator and motor generator sets, all assume these same extremes of power factors.

Examination of the load demands of various military aircraft types indicates that the maximum single probable 400 Hz load will not exceed 100 amps per line. Therefore, calculations are largely based on this maximum individual load.

The voltage drop in and any one section of the distribution network will be:

$$\Delta V = I \times Z$$

where  $\Delta V$  is the voltage drop  
 $Z$  is the complex impedance of the network component  
 $I$  is the complex current

For resistive loads,  $\Delta V = I \times R$

$$\begin{aligned} \text{For 0.8 power factor loads, } \Delta V &= |I| \times (0.8 - j.6) \times (R + jwL) \\ &= |I| [(0.8R + 0.6wL) + j(0.8wL - 0.6R)] \end{aligned}$$

The maximum permitted voltage drop is 4.8 VAC or 4.17 percent of input voltage. The out-of-phase component of voltage drop cannot exceed the total voltage drop, because for all practical components  $(0.8R + 0.6wL)$  is larger in value than  $(0.8wL - 0.6R)$ . Therefore, the maximum out-of-phase voltage is less than 4.17 percent.

The error in output voltage cannot exceed

$$\sqrt{(1.00)^2 + (0.0417)^2} - 1 = 0.00087$$

The error is thus less than 0.1 percent, and therefore, the out-of-phase term can be ignored without any significant loss in accuracy. The following is therefore used in calculation of voltage drops at 0.8PF:

$$\Delta V = (0.8R + 0.6wL) \times I$$

Component parts of the distribution system are: (Refer to Figure 2, Page 49 illustrating a typical system). (Refer to one-line diagram, Figure 1, Page 48).

- a. High voltage line which is the high voltage (nominal 4160 VAC) power line connecting switchgear to the utilization transformers. Tables are provided listing voltage drops versus load current and distance. There will typically be several sections in the high voltage line, with branches at end of each section, connecting to the utilization transformers. The voltage drop in each section must be selected or computed, and the sum of all section drops provides the actual total voltage drop. Wire sizes for which data is offered range from No. 6 AWG to No. 4/0, in aluminum and copper.
- b. Utilization transformers are specified with ratings which are 60, 75, 90, 120 and 150 KVA. Tables are offered providing AC voltage drops.

- c. The low voltage line connects the output of the utilization transformers to the circuit breaker which, in turn, connects to the load cable. Data is provided for wires sizes from No. 2 AWG through No. 4/0, listing voltage drop versus current and distance. If there are branches on this line, each section must have a separate voltage drop calculation and all voltage drops are summed to provide the total voltage drop.
- d. Load cable connects 400 Hz power to the aircraft. Voltage drop data is provided for wire sizes No. 2 AWG through No. 4/0.

Tables of data are provided which are:

Table 2, Page 43 - High voltage line data provides information on triplexed 5KV shielded aluminum cable of the type recommended for use on the 4160 VAC distribution system.

Table 3, Page 44 - Same as Table 2, Page 43, but for copper conductors.

Table 4, Page 45 - Same as Table 3, Page 44, except for 600 volt with ground or neutral wires for use in the low voltage line. Items 15, 16 and 17 require explanation. Item 15 is the effective impedance for an 0.8PF, 400 Hz load. It is obtained by the equation:

$$Z_{0.8} = 0.8R(400 \text{ Hz}) + 0.6(X_L)(400 \text{ Hz}) \text{ where } R \text{ is obtained from Line 10 and } X_L \text{ from Line 14.}$$

Item 16 is obtained by multiplying Line 10 by  $100 \times 0.0025 \times (100/115)$  to obtain percent voltage drop per 1000 feet of high voltage line per 100 amps of load at 115 VAC level.

The 0.0025 factor is the impedance transfer ratio of the utilization transformers which is a 20 to 1 ratio and hence the impedance ratio is  $(1/20)^2$ .

Line 17 is the same as Line 16 except the factor is applied to Line 15 to obtain the percent voltage drop per 1000 feet for each 100 amps of 0.8 power factor load current.

Table 5, Page 46 - Provides impedance and voltage drop data on the utilization transformers. Again, the factor  $100 \times 0.0025 \times (100/115)$  was applied to the 400 Hz R and to the effective impedance for 0.8 power factor loads to obtain percent voltage drop per 100 amps of load current.

The voltage source will be maintained at 117.4 VAC, plus or minus 0.6 VAC. The minimum voltage is 116.8 VAC. The minimum voltage at the skin of the aircraft is 112 VAC. The maximum drop permitted is  $116.8 - 112.0 = 4.8$  VAC. As a percent of nominal voltage, this is  $100 \times (4.8/115) = 4.17$  percent.

By use of the above tables, the voltage drop in the system may readily be determined.

## 2.19

## HIGH VOLTAGE POWER LINE HARMONICS.

Harmonic voltage resonance in the high voltage line is considered to present a potential problem. Therefore, the capacitances and inductances in the high voltage line are computed or estimated and an appropriate filter will be used to minimize effects of such resonance.

$$\text{Capacity} = \frac{1}{0.281 \log \frac{2D}{d}} \quad \text{picofarads per foot}$$

where  $D$  = distance between conductor = 0.6 inches  
 $d$  = diameter of conductor = 0.3 inches

$$\log \frac{2 \times 0.6}{0.3} = \log 4 = 0.6$$

$$C = \frac{1}{0.281 \times 0.6} = 5.93 \text{ picofarads per foot}$$

Line-to-line capacity for total 32,000 feet of high line is  $32,000 \times 5.93 \times 10^{-6}$  microfards = 0.19 microfarads.

Line-to-imaginary neutral capacity =  $3 \times 0.19 = 0.57$  microfarads.

$Z$  at 400 Hz = 701 ohms.

KVA in this one line = 8.2

Total KVA in capacity of high line is 24.6 KVA for 32,000 feet total.

Inductance of main transformers is equivalent to two percent impedance in 325 KVA transformer =  $0.02 \times 53$  ohms = 1.06 ohms.

$$\text{This will resonate to harmonic} = \sqrt{\frac{Z_c}{Z_l}} = \sqrt{\frac{701}{1.06}} = 25\text{th}$$

With a second central power 400 Hz transformer on line, and with numerous other load transformers on line, the frequency of the harmonic to which the system will resonate will move higher. The interwinding capacity of the transformers will significantly increase the capacitance of the high voltage system, thus reducing the harmonic to which the system will resonate. The only high frequency harmonics present in generator output which could cause a problem are the 17th and 19th. Therefore, a filter will be included on the

4160 VAC, 400 Hz bus as a part of each central power 400 Hz transformer. The filter will be tuned to the 17th harmonic of 400 Hz and will be damped to have a "Q" of less than 4. Estimated maximum current will be based on 7 percent of the generator output or 7.5 KVA per line. A 0.5 mfd, 5000 VAC capacitor will be connected in series with an inductor and connected on each high voltage line to ground. The inductor value will be approximately 1 millihenry rated to carry a maximum current of 10 Amps AC. The resistor value will be 200 ohms connected across the inductor, and will be rated for 1 KW maximum power dissipation. It will be operated at less than half of its KW rating. This set of values will effectively damp the 17th harmonic and all higher order harmonics which could otherwise resonate on the distribution system.

## 2.20 LIGHTNING PROTECTION.

High voltage transients, due to lightning, represent not only a hazard to the 400 Hz power generation and distribution system, but also to the aircraft electronics systems. Lightning is not a serious hazard to the aircraft electronic systems with the present 400 Hz ground power system. Therefore, the direction of this study considers protection of the expensive aircraft electronic systems as a primary objective in the design of the lightning protection measures recommended herein.

Standards of insulation have been established for 60 Hz systems. As protection for the 400 Hz power generation and distribution system, JB & B believes they are adequate. These standards are not adequate for protection of the load circuits and this additional protection will be considered separately.

Table 6 on Page 47 lists test requirements which have been established as industry standards for 60 Hz electrical equipment in the 5KV class of insulation and operation. These standards will be applied in specifications for the equivalent 400 Hz components.

The 25KV BIL test for transformers, line drop compensators and motor generator sets, is low as compared to the capability of the high voltage line which can tolerate a BIL test of several hundred thousand volts. Protection must be placed as close as practical to these components. The most cost effective protection for the low BIL test components appears to be spark gap type protectors located within the enclosures. Where line drop compensators are used, they are planned to be within the housing of transformers. Thus, spark gap type lightning protection will protect both the transformer and the line drop compensator. A close by earth ground should be made to bypass lightning derived current surges with as little voltage excursion as practical. The earth ground preferably will be within 50 feet of the transformer. Thus, one ground can serve only a limited number of utilization transformers.

The motor generator sets will always be located close to switchgear to control the 400 Hz output power. Spark gap type lightning protection should be located within the switchgear housing to protect switchgear, motor generator sets and the step-up transformers if these are used. An earth ground must be located within 50 feet.

Earth grounds must be designed to be in conductive soil with heavy enough conductors to effectively bypass lightning current surges.

The windings of a 5KV motor generator set are difficult to protect. It is recommended that capacitors be placed at the output terminals to limit the maximum possible rate of rise of voltage induced by lightning at these points. Alternately, do not use generators with 4160 VAC directly from the output.

The use of surge limiting capacitors at these locations also will protect the motor generator sets from voltage spikes such as can be induced from use of vacuum interrupters in the load circuit. Vacuum interrupters frequently will interrupt currents which are not near zero, and consequently, can cause voltage spikes which will breakdown transformer or motor generator set insulation. It will be the responsibility of the motor generator set manufacturer to provide adequate lightning protection.

The utilization transformers used in the 400 Hz distribution system are of shielded design. Consequently, there will be virtually no transfer of charge by capacitive action from primary windings to secondary windings. The transfer of voltage impulse via the turns ratio of the transformer provides a 20:1 stepdown. Thus, if the lightning protection on the primary side limits voltage surges to 25KV, the secondary surge of voltage will not exceed 1.25KV.

MIL-STD-704B, Paragraph 6.2, limits voltage spikes to a maximum of plus or minus 600 volts for not more than 50 microseconds. Standard lightning protection recognizes this same 50 microsecond time interval in the standard BIL tests. This 600 volt maximum limit is approximately half of the expected 1250 volt peak output possible by turns ratio of the stepdown transformer. Therefore, it will be necessary to provide bypass capacitors on the output of the stepdown transformers to limit the voltage spikes to less than 600 volts. With transformers of the impedance specified, a 75 KVA transformer will require approximately 25 microfarads on each line-to-ground to provide this protection. It will be made the responsibility of the transformer supplier to demonstrate that adequate filters are included to satisfy this requirement.

Protection of the aerial cables is by grounding both the messenger cable and the shield at every cable support location. No open wire should be used in the 4160V, 400 Hz distribution system. Attention must be given to the quality of the grounds to make certain they are adequate.

## SHORT CIRCUIT PROTECTION.

The protective circuits must provide a situation in which a short circuit or severe overload will interrupt the short circuit with a minimum disruption to other equipment operating from the same power distribution line, and further, no consequential damage can be permitted to electrical components other than the one in which the fault occurred.

The 400 Hz system is generally easier to protect than is the equivalent 60 Hz system, primarily because of the inherent source impedance of the motor generator sets, which limits the maximum let-through current. The peak let-through current of the generator will occur always on the first full half cycle. Thereafter, the current decreases exponentially to a steady-state value which will tend to be approximately 60 percent of the first full half cycle peak current. This characteristic is a function of the 400 Hz generator design and particularly the design of the damper cage. For simplicity in conducting this analysis, the exponential decrease in current will be ignored and the impedance of each generator will be assumed a constant 20 percent with a 0.3 power factor impedance. Thus, on a per unit basis for 313 KVA generators,  $Z = |0.2| = 0.06 + 0.19j$ .

With four generators in parallel, the total per unit impedance will be  $0.015 + 0.0475j = |0.5|$ . Maximum current will then be  $E/|0.5| = 20$  times rated current of a single generator. A single generator has rated current of 44 amps at 4160V. Hence, the maximum instantaneous full half cycle of current would be  $20 \times 44 = 880$  amps RMS. This value is well below the interrupting rating of high voltage circuit breakers and fuses. A typical 5KV circuit breaker has an interrupting rating of 8,800A RMS at rated voltage. Further, the energy which can be stored in power line and transformer in a 400 Hz system tends to be in a 60/400 ratio as compared to that in an equivalent 60 Hz system. Hence, the energy to be absorbed by the fuse, contactor or circuit breaker in clearing the short is very much reduced, as compared to the energy to be absorbed in an equivalent 60 Hz fault clearing process.

The DC component of fault current cannot exceed the peak AC fault current. The energy in this DC component is low as compared to the equivalent 60 Hz circuit because it is stored in the system inductances, which are necessarily low as compared to the equivalent 60 Hz system.

These factors in combination indicate that fault clearing and associated DC current components will not be a problem in the 400 Hz distribution system.

Short circuit calculations are made for the arrangement described in the engineering calculations of Paragraph 2.17 for Condition (C), Page 26. This is a 16,000 feet high voltage line with load take offs at each 2,000 feet connecting through 75 KVA transformers.

The following impedances are in line for Position Number 1 which is 2,000 feet from the generating plant.

Per unit generator impedance is  $0.015 + 0.0475j$  line-to-imaginary neutral. Actual impedance will be:

$$\begin{aligned} E^2/KVA &= (2400)^2/(312)/3 \times (0.015 + 0.0475j) = 55(0.015 + 0.0475j) \\ &= (0.825 + 2.6j) \end{aligned}$$

This is the transient impedance for a group of four paralleled generators.

At the 115/200 VAC level, this is multiplied by 0.0025 which provides:

$$Z_g + Z_{11} = 0.0025(0.825 + 2.6j) = 0.002 + 0.0065j$$

$$Z_{21} = 2,000 \text{ feet of high voltage cable} = 0.0006 + 0.0011j$$

$$Z_{31} = 75 \text{ KVA transformer impedance} = 0.005 + 0.0125j$$

$$Z_{41} = 75 \text{ feet of low voltage line} = 0.005 + 0.014j$$

$$Z_{51A} = 50 \text{ feet of Number 2 load cable} = 0.007 + 0.009j$$

A short circuit directly at the secondary of the utilization transformer will be through  $Z_g + Z_{11} + Z_{21} + Z_{31}$ .

$$Z_{T1} = 0.0076 + 0.02j$$

$$|Z_{T1}| = 0.021$$

With source E of 118 VAC:

$$I_{\text{fault}} = 118/0.021 = \underline{5619 \text{ amps RMS maximum}}$$

A fault at the end of the load circuit breaker will be through impedances  $Z_g + Z_{11} + Z_{21} + Z_{31} + Z_{41}$ .

$$Z_{T2} = 0.0126 + 0.0211j$$

$$|Z_{T2}| = 0.0250$$

$$I_{\text{fault}} = 118/0.0256 = \underline{4609 \text{ amps AC maximum}}$$

If the fault is at the end of the load cable (at the aircraft), the fault will be in series with  $Z_g + Z_{11} + Z_{21} + Z_{31} + Z_{41} + Z_{51A}$ .

$$Z_{T3} = 0.0196 + 0.0431j$$

$$|Z_{T3}| = 0.047$$

$$I_{\text{fault}} = 118/0.047 = \underline{2510 \text{ amps maximum}}$$

Faults which occur farther from the generating plant will provide progressively lower fault currents. Thus, if breaker coordination is properly planned at the nearest load center, it will be adequate everywhere. It will be observed that the high voltage cable made the lowest contribution of impedance.

Hence, fault currents will not increase significantly for shorter lines, nor decrease significantly for long runs.

The low voltage circuit breaker recommended in this study is the 225 amp molded case "J" frame unit with an interrupting rating of 10,000 amps minimum.

TABLE 1

## MILITARY STANDARD 704B SUMMARY OF ELECTRICAL CHARACTERISTICS FOR 3 PHASE, 400 HZ AIRCRAFT POWER

Item No.	Electrical Characteristics	Limits	Paragraph
1	Voltage Range Normal at Point of Utilization within Aircraft	108-118	5.1.1.1
2	Voltage Range Average of Three Phases	108-118	
3	Voltage Unbalance	3 VAC	5.1.1.2
4	Voltage Phase Unbalance	$120^\circ \pm 2^\circ$	5.1.1.3
5	Phase Sequence	A-B-C	5.1.1.4
6	Waveform	-----	5.1.1.5
	a. Individual Harmonic Content	2.75%	Figure 2
	b. DC Component	$\pm 0.1$ VAC	
	c. Waveform Formula	$\pm 0.071 + \sin \theta$	
7	Amplitude Modulation	0.62 VAC RMS	5.1.1.6
8	Frequency Components of Voltage Modulation	Side band $400 \pm 60$ Hz but no re-duction higher	5.1.1.6
9	Frequency Range, Normal	$400 \pm 5$ Hz	5.1.1.7
10	Frequency Range for Helicopters	$400 \pm 20$ Hz	5.1.1.7
11	Frequency Drift Limit	15 Hz per minute	5.1.1.7

TABLE 1 (Continued)

Item No.	Electrical Characteristics	Limits	Paragraph
12	Frequency Modulation	$\pm 5$ Hz and Figure 3	5.1.1.8
13	Frequency Transient	$\pm 25$ Hz	5.1.3
14	Rate of Change in Frequency	500 Hz per second	5.1.3
15	Voltage Transient 10% Load to 85% and Return - Limit 10 $\mu$ sec duration	80-180 VAC	5.1.2.1
16	Voltage Spikes	600 peak volts	6.2

TABLE 2. DATA FOR ALUMINUM CABLE, 5KV, SHIELDED, TRIPLEXED, 400 HZ OPERATION

Item	Description	Wire Size --				1	1/0	2/0	3/0	4/0	Note
1	S = Single Conductor O.D.					.75	.79	.89	.94	1.00	1
2	D = Diameter of Conductor					.332	.373	.419	.470	.528	3
3	RDC at 20° C ohms per 1000 feet					.265	.210	.167	.133	.105	3
4	DC Resistance at 40° C					.286	.227	.180	.143	.113	3
5	60 Hz Ampacity					139	157	182	207	237	3
6	$B = \sqrt{\text{Hz}/\text{RDC}}$					37	41	46	52	59	4
7	K = D/S					.44	.47	.47	.50	.528	4
8	X = 0.0276 x B					1.02	1.13	1.27	1.44	1.63	4
9	400 Hz R Multiplier					1.013	1.016	1.020	1.038	1.075	4
10	400 Hz R (40° C)					.289	.231	.184	.148	.121	4
11	400 Hz Ampacity Factor					.987	.984	.980	.963	.930	5
12	400 Hz Ampacity					139	156	180	205	231	5
13	L/Lo =					.997	.996	.995	.990	.983	4
14	400 Hz Reactance = $X_L$					.269	.259	.259	.250	.242	4
15	$\bar{X}0.8 = 400 \text{ Hz Impedance}$					.392	.340	.302	.268	.242	6
16	Percent Voltage Drop per M feet, 1.0PF					.063	.050	.040	.032	.026	7
17	Percent Voltage Drop per M feet, 0.8PF					.085	.074	.066	.058	.053	8

Notes:

- 1 Data from Kaiser catalog.
- 2 Data from ITT catalog.
- 3 Data from Okonite catalog.
- 4 Reference article by B. J. Mulvey in Appendix J.
- 5 Ampacity multiplier  $= \sqrt{1/R}$  factor
- 6 Effective impedance for 0.8PF load,  $\bar{X} = 0.8R + 0.6(X_L)$
- 7 Percent voltage drop for 1.0 power factor load per 100 amps.  $(R \times \text{Amps at } 115/200 \times 0.0025)/1.15$
- 8 Percent voltage drop for 0.8 power factor load per 100 amps.  $(\bar{X}0.8 \times \text{Amps at } 115/200 \times 0.0025)/1.15$

TABLE 3. DATA FOR COPPER CABLE, 5KV, SHIELDED, TRIPLEXED, 400 HZ OPERATION

Item	Description	Wire Size →	6	4	2	1	1/0	2/0	3/0	4/0	Note
1	S = Single Conductor O.D.		.55	.60	.68	.72	.76	.80	.91	.96	1
2	D = Diameter of Conductor		.184	.232	.292	.332	.373	.419	.470	.528	3
3	RDC at 20° C ohms per 1000 feet		.403	.253	.159	.126	.100	.0795	.0630	.050	3
4	RDC at 40° C ohms per 1000 feet (1.08)		.435	.273	.172	.136	.108	.086	.068	.054	3
5	60 Hz Ampacity (40° C)		97	127	167	194	223	257	296	342	3
6	$B = \sqrt{\text{Hz}/\text{RDC}}$		30	38	48	54	61	68	76	86	4
7	$K = D/S$		.335	.387	.429	.461	.518	.524	.516	.55	4
8	$X = 0.0276 \times B$		.82	1.04	1.32	1.49	1.68	1.87	2.10	2.37	4
9	400 Hz R Multiplier		1.004	1.013	1.035	1.05	1.08	1.14	1.19	1.25	4
10	400 Hz R		.437	.276	.178	.143	.117	.098	.081	.067	4
11	400 Hz Ampacity Factor		.998	.993	.983	.976	.962	.936	.917	.894	5
12	400 Hz Ampacity		97	126	164	189	214	241	269	305	5
13	$L/L_o =$		.998	.997	.992	.987	.979	.967	.953	.925	4
14	400 Hz Reactance = $X_L$		.312	.290	.274	.263	.253	.244	.242	.233	4
15	$X_{0.8} = 400 \text{ Hz Impedance}$		.537	.395	.306	.272	.246	.224	.210	.194	6
16	Percent Voltage Drop per M feet, 1.0PF		.095	.060	.039	.031	.025	.021	.018	.014	7
17	Percent Voltage Drop per M feet, 0.8PF		.117	.086	.066	.059	.053	.049	.046	.042	8

Notes:

- 1 Data from Kaiser catalog.
- 2 Data from ITT catalog.
- 3 Data from Okonite catalog.
- 4 Reference article by B. J. Mulvey in Appendix J.
- 5 Ampacity multiplier  $= \sqrt{1/R}$  factor
- 6 Effective impedance for 0.8PF load,  $X = 0.8R \pm 0.6(X_L)$
- 7 Percent voltage drop for 1.0 power factor load per 100 amps.  $(R \times \text{Amps at } 115/200 \times 0.0025)/1.15$
- 8 Percent voltage drop for 0.8 power factor load per 100 amps.  $(R \times 0.8 \times \text{Amps at } 115/200 \times 0.0025)/1.15$

TABLE 4. DATA FOR COPPER CABLE, 600 VOLT, TRIPLEXED, ARMORED CABLE WITH NEUTRAL, 400 HZ OPERATION

Item	Description	Wire Size →		1	1/0	2/0	3/0	4/0	Note
1	S = Single Conductor O.D.			.49	.54	.58	.63	.69	1
2	D = Diameter of Conductor			.332	.373	.419	.470	.528	3
3	RDC at 25° C ohms per 1000 feet			.129	.102	.0811	.0642	.0509	3
4	RDC at 90° C ohms per 1000 feet (1.25 multiplier)			.161	.127	.101	.080	.064	3
5	60 Hz Ampacity			141	166	190	218	255	3
6	$B = \sqrt{\text{Hz}/\text{RDC}}$			49	57	64	70	80	4
7	K = D/S			.678	.690	.722	.746	.765	4
8	X = $0.0276 \times B$			1.35	1.57	1.76	1.93	2.2	4
9	400 Hz R Multiplier			1.05	1.08	1.15	1.22	1.33	4
10	400 Hz R-			.169	.137	.116	.098	.085	4
11	400 Hz Ampacity Factor			.976	.962	.932	.905	.867	5
12	400 Hz Ampacity			120	135	171	189	214	5
13	L/Lo =			.998	.992	.973	.965	.944	4
14	400 Hz Reactance = $X_L$			.210	.201	.193	.188	.183	4
15	$X_{0.8} = 400 \text{ Hz Impedance}$			.291	.257	.209	.191	.178	6
16	Percent Voltage Drop per foot, 1.0PF			.018	.015	.010	.008	.007	7
17	Percent Voltage Drop per foot, 0.8PF			.025	.022	.018	.017	.015	8

Notes:

- 1 Data from Kaiser catalog.
- 2 Data from ITT catalog.
- 3 Data from Okonite catalog.
- 4 Reference article by B. J. Mulvey in Appendix J.
- 5 Ampacity multiplier =  $\sqrt{1/R}$  factor
- 6 Effective impedance for 0.8PF load,  $X = 0.8R + 0.6(X_L)^2$
- 7 Percent voltage drop for 1.0 power factor load per 100 amps per foot for 115 VAC power.
- 8 Percent voltage drop for 0.8 power factor load per 100 amps per foot for 115 VAC power.

TABLE 5. POWER TRANSFORMER IMPEDANCES

Item	Description	KVA	60	75	90	120	150	Note
1	Shunt Losses, KW		1.2	1.4	1.65	2.04	2.40	1
2	Series R		.0063	.0050	.004	.003	.0025	1
3	Series Reactance		.0156	.0125	.010	.008	.0062	1
4	Voltage Drop, 1.0PF per 100 Amps		.630	.500	.400	.320	.2500	2
5	Voltage Drop, 0.8PF per 100 Amps		1.44	1.15	1.00	.720	.5700	3
6	Percentage Drop, 1.0PF per 100 Amps		.548	.435	.348	.274	.2170	4
7	Percentage Drop, 0.8PF per 100 Amps		1.250	1.00	.910	.625	.5000	-

Note:

- 1 Limits set by transformer specifications.
- 2 Calculated by  $100 \times R = \Delta E$ .
- 3 Calculated by  $(0.8R + 0.6X) \times 100 = \Delta E$ .
- 4 Column 4/1.15 = % drop per 100 amp load.
- 5 Column 5/1.15 = % drop per 100 amp load.

TABLE 6. BASIC IMPULSE LEVELS OF VARIOUS APPARATUS FOR 5KV OPERATION

Item	Component Type	Hi Pot 60 Hz KV	BIL Test KV (1.2 x 50)	Flashover Test Volts	Bushings Withstand Voltage			Note
					One Min. Dry (60 Hz)	10 Set Wet (60 Hz)	BIL (1.5 x 40)	
1	Dry Transformer	12	25	---	---	---	---	1
2	Liquid Filled Transformer	19	60	69	21	20	60	-
3	Power Circuit Breakers	--	60	---	---	---	---	2
4	Cable Potheads	19	60	69	21	20	60	-
5	Distribution Cables	19	60	---	---	---	60	-
6	Line Drop Compensators	12	25	---	---	---	---	3
7	Motor-Generator Sets	12	25	---	---	---	---	4

Note:

- 1 Values are for distribution transformers, instrument transformers and voltage regulators.
- 2 Values are for switchgear assemblies, power circuit breakers, metal enclosed buses and fuse assemblies.
- 3 For 5KV operation, this is the proposed test level to be compatible with the dry type distribution transformers.
- 4 No standards established for 5KV motor generator sets. This is proposed in order to be compatible and equivalent to the other high voltage 400 Hz components.

Reference: Data derived from IEEE Transactions on Industry Applications dated April 1973 entitled "A Review of Lightning Protection and Grounding Practices" by George W. Walsh.

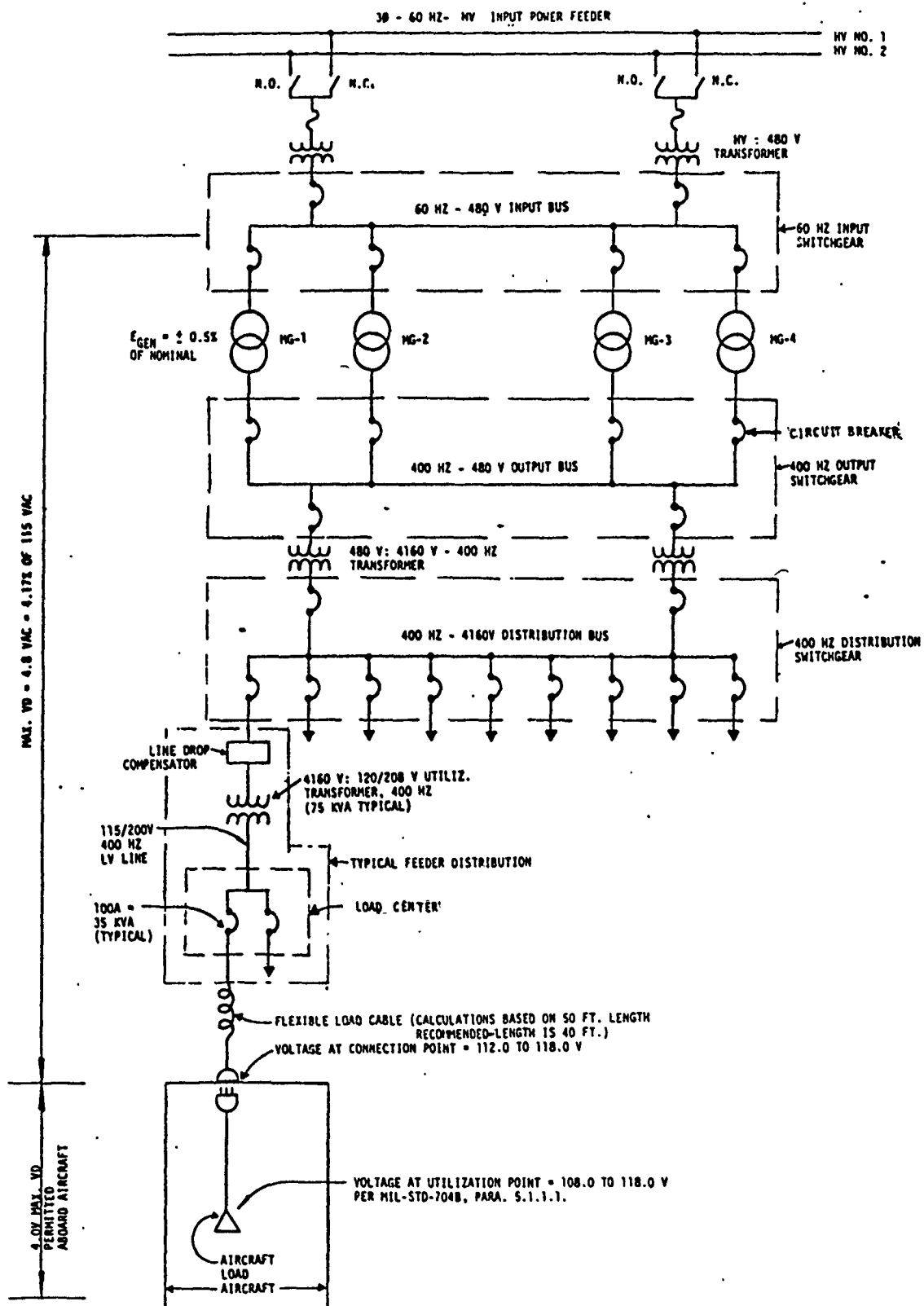
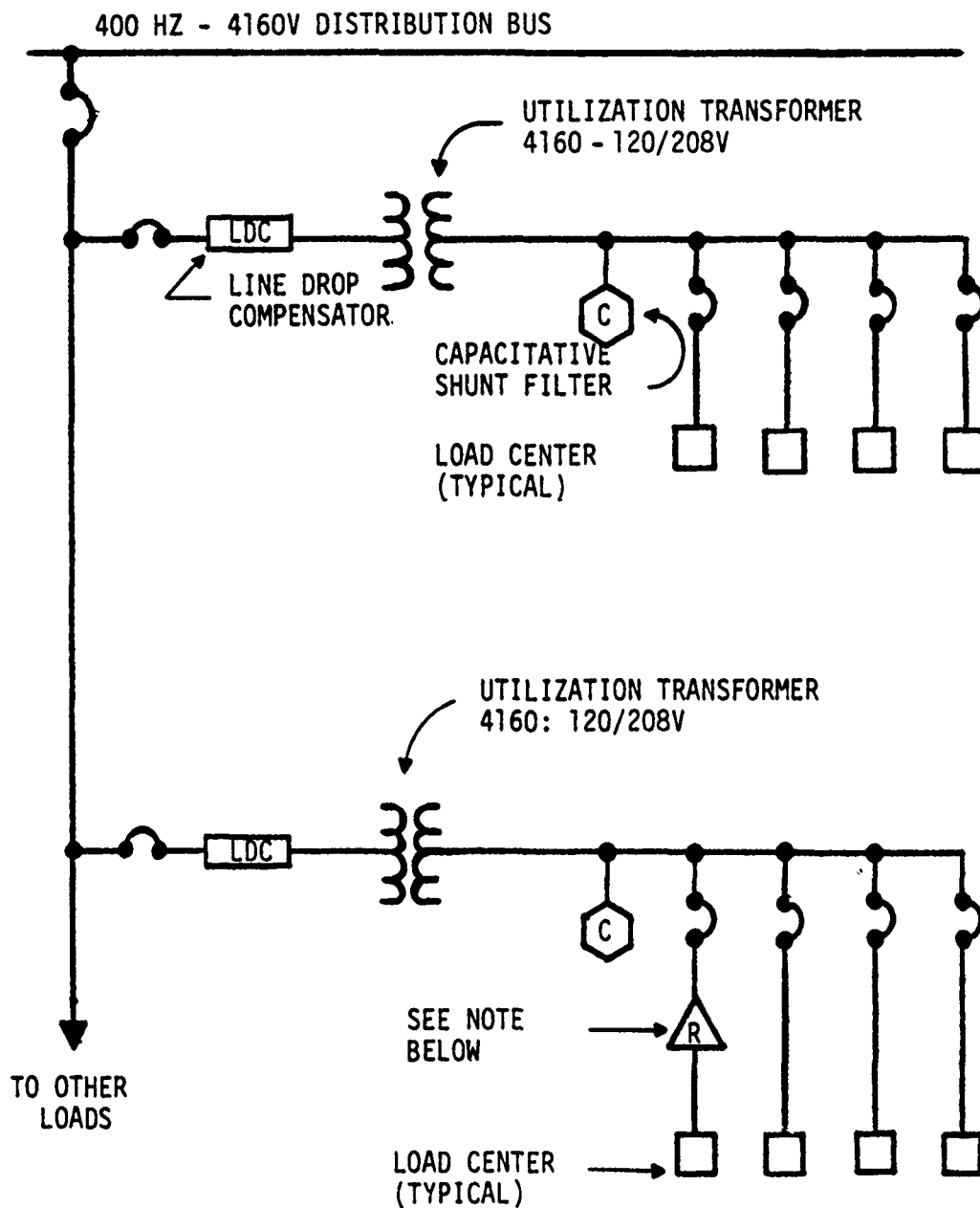
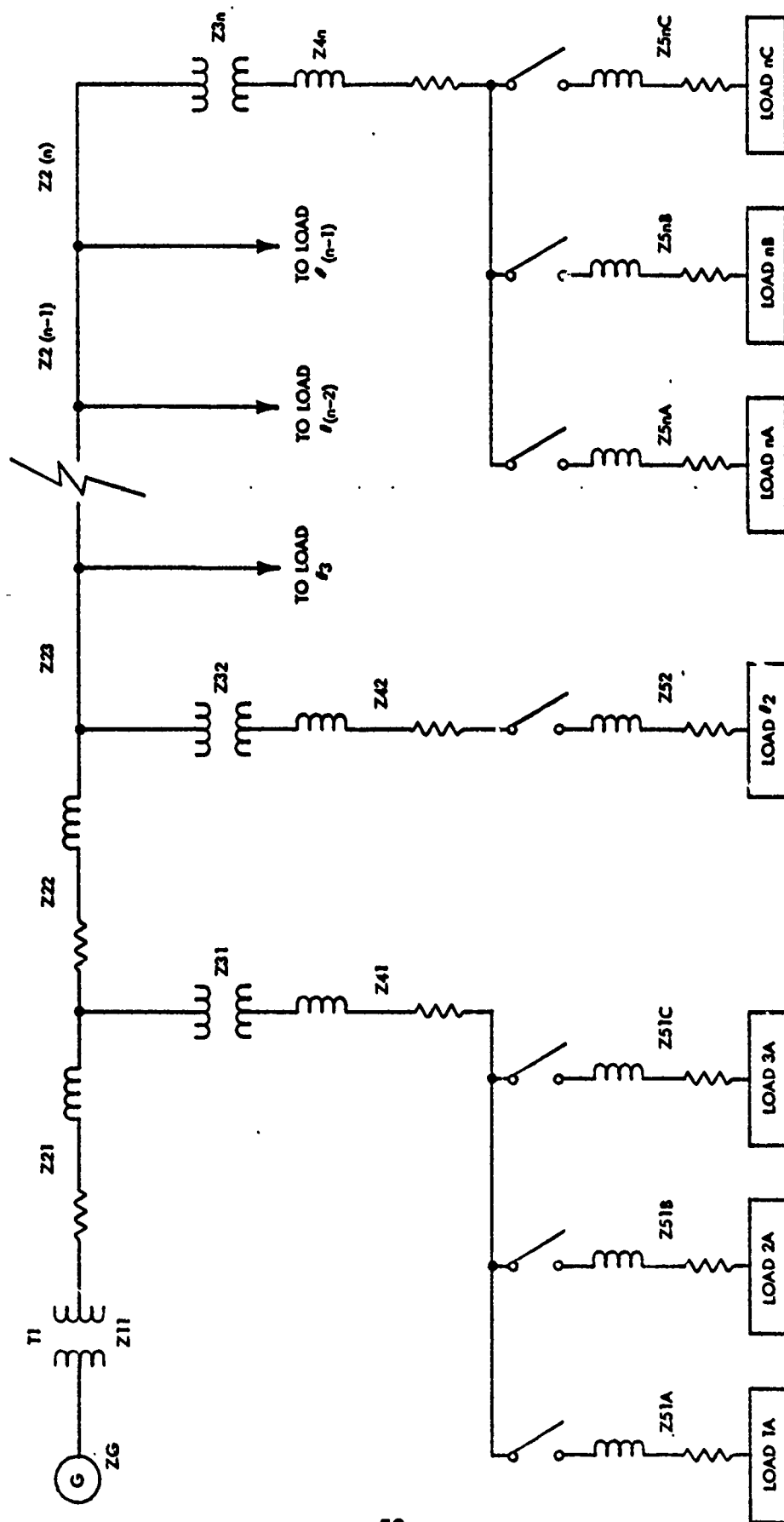


FIG 1  
ONE LINE DIAGRAM  
400 HZ POWER GENERATING CENTRAL PLANT



**NOTE:** ELECTRONIC VOLTAGE REGULATORS MAY BE USED ONLY IN SPECIAL SITUATIONS - REFER TO PARA. 2.6 - PAGE 14 AND 2.13.b. - PAGE 19.

FIGURE 2  
ONE LINE DIAGRAM  
400 HZ POWER DISTRIBUTION TO LOAD CENTERS



IMPEDANCE DIAGRAM 400 HZ DISTRIBUTION SYSTEM.

FIGURE 3

### SECTION 3 - ECONOMIC ANALYSIS INDEX

#### 3.1 PRIMARY ECONOMIC ANALYSIS

Alternative "A" - Existing Individual Motor Generators

Alternative "B" - Proposed 400 Hz Centralized Plant

#### 3.2 SECONDARY ECONOMIC ANALYSIS

Alternative "A" - Centralized 400 Hz System - Motor Generators -  
Low Voltage

Alternative "B" - Centralized 400 Hz System - Motor Generators -  
High Voltage

Alternative "C" - Centralized 400 Hz System - Solid State - High  
Voltage

3.1 PRIMARY ECONOMIC ANALYSIS - COMPARISON OF EXISTING INDIVIDUAL MOTOR GENERATORS VERSUS CENTRALIZED 400 HZ GENERATING SYSTEM

3.1.1 Design Alternatives.

- a. Existing individual motor generator units
- b. Centralized 400 Hz generating system

3.1.2 Analysis Summary.

	<u>Alternatives</u>	
	<u>"A "</u>	<u>"B "</u>
Initial Investment:	\$3,659,867	\$1,523,000
Discounted Annual Cost:	<u>4,869,095</u>	<u>1,619,826</u>
Total Present Value:	<u>\$8,528,962</u>	<u>\$3,142,826</u>

3.1.3 Conclusion.

Alternative "B" has a tremendous economic advantage over Alternative "A" due to significant savings to operating and maintenance costs.

3.1.4 Recommendation.

Alternative "B".

3.1.5 Initial Investment - Alternative "A" (Existing).

Annual replacement cost of fixed and mobile equipment is based on the assumption that 10 percent of the existing equipment will be replaced annually, and is as follows:

Fixed Equipment:

$$10\% \text{ of } 3,830 \text{ KVA} = 383 \text{ KVA} @ \$250/\text{KW} = \$95,750$$

Mobile Equipment:

$$10\% \text{ of } 6,480 \text{ KVA} = 648 \text{ KVA} @ \$560^*/\text{KW} = \$362,880$$

$$\text{Total Annual Cost} \quad \underline{\underline{\$458,630}}$$

From Table B - Present-Value Table, Appendix D, NAVFAC P-442, the "cumulative uniform series" factor of 7.980 is selected. (Inflation rate if not considered; Discount rate 10 percent annually for 15 years).

$$\text{Discounted Annual Cost} = \$458,630 \times 7.980 = \underline{\underline{\$3,659,867}}$$

\* Per Appendix C (\$560 per KW).

3.1.6 Initial Investment - Alternative "B" (New).

Per Appendix E: \$1,523,000

3.1.7 Operating Costs.

3.1.7.1 Alternative "A".

a. Fixed Equipment:

$$414 \text{ KW} \times 8760 \text{ Hours} = 3,626,640 \text{ KWH} \times \$0.04/\text{KWH} = \$145,066$$

Annual Cost

b. Mobile Equipment:

$$52 \text{ KW} \times 8760 \text{ Hours} = 455,520 \text{ KWH} \times \$0.39/\text{KWH} = \$177,653$$

Annual Cost

3.1.7.2 Alternative "B".

a. Fixed Equipment:

$$280 \text{ KW} \times 8760 \text{ Hours} = 2,452,800 \text{ KWH} \times \$0.04/\text{KWH} = \$98,112$$

b. Mobile Equipment:

$$13 \text{ KW} \times 8760 \text{ Hours} = 113,880 \text{ KWH} \times \$0.39/\text{KWH} = \$44,413$$

3.1.8 Maintenance.

Maintenance costs including spare parts replacement are based on the assumption that the average cost per unit per month is \$100.00 for fixed equipment and \$115.00 for mobile equipment. These values are considered to be very low.

3.1.8.1 Alternative "A".

a. Fixed Equipment:

$$54 \text{ MGs} \times \$100 \times 12 \text{ months} = \$ 64,800$$

b. Mobile Equipment:

$$92 \text{ MGs} \times \$115 \times 12 \text{ months} = \underline{\$126,960}$$

\$191,760 Annual Cost

3.1.8.2 Alternative "B".

a. Fixed Equipment:

$$4 \text{ MGs} \times \$100 \times 12 \text{ months} = \$ 4,800$$

b. Mobile Equipment:

$$23 \text{ MGs} \times \$115 \times 12 \text{ months} = \underline{\$31,740}$$

\$36,540 Annual Cost

Note: Assume 25 percent of total present capacity of the mobile equipment remains in use. The, 25 percent of 6,480 KVA = 1,620 KVA @ 70 KVA average rating = 23 MGs.

3.1.9 Discounted Annual Costs.

(Present worth of O and M costs).

3.1.9.1 Operations.

a. Electricity. From Table B - Present-Value Table of Appendix D, NAVFAC P-442, the "cumulative uniform series" factor of 7,980 is selected. (Inflation rate is not considered; Discount rate 10 percent annually for 15 years).

b. Fuel. From Table 7 of Appendix E, NAVFAC P-442, the "cumulative uniform series" factor of 12.278 is selected. (Inflation rate of 7 percent; Discount rate of 10 percent annually for 15 years).

3.1.9.2 Maintenance.

From Table B - Present-Value Table, Appendix D, NAVFAC P-442, the "cumulative uniform series" factor of 7.980 is selected. (Inflation rate is not considered; Discount rate 10 percent annually for 15 years).

3.1.9.3 Discounted Annual Costs.

a. Operating Costs - Electricity:

<u>Alternative "A"</u>	<u>Alternative "B"</u>
$7.98 \times (145,066) = \$1,157,627$	$7.98 \times (98,112) = \$782,934$

b. Operating Costs - Fuel:

$12.278 \times (177,653) = \$2,181,223$	$12.278 \times (44,413) = \$545,303$
---	--------------------------------------

c. Maintenance Costs:

$7.980 \times (191,760) = \underline{\$1,530,245}$	$7.980 \times (36,540) = \underline{\$291,569}$
Discounted Annual Costs \$4,869,095	\$1,619,826

3.2 SECONDARY ECONOMIC ANALYSIS PREPARED IN ORDER TO ESTABLISH THE TYPE AND VOLTAGE LEVEL OF 400 HZ CENTRAL GENERATING PLANT.

3.2.1 Design Alternatives.

- a. Motor Generators (Low Voltage). This alternative requires that the 60 Hz input voltage to the motor generator unit be stepped down to 480 VAC from the primary line which is expected to be in the range of 5KV to 15KV.
- b. Motor Generators (High Voltage). This alternative consists of a motor generator unit with 4160 VAC input and output. This alternative does not require input voltage transformation since the motor generator unit operates directly at the available input voltage level. This alternative is limited to a maximum 60 Hz input voltage of nominal 5KV, as it is not practical to use motors of higher voltage rating in the required horsepower range.

In each and every case which requires voltage transformation of the incoming 60 Hz power, the voltage transformation should always be down to the 480 VAC level to permit use of the standard motor generator unit and, therefore, in such cases Alternative "A" applies.

- c. Solid-State Frequency Converter (High Voltage). This alternative consists of a solid-state frequency converter with high voltage input (4160 VAC or higher) and 4160 VAC/400 Hz output. Voltage transformation is not required since the solid-state frequency converter provides the required voltage transformation which may be at 4160 VAC or higher through the use of an isolation transformer whose initial cost and losses are included in the economic analysis.

3.2.2 Analysis Summary.

	<u>Alternatives</u>		
	<u>"A "</u>	<u>"B "</u>	<u>"C "</u>
Initial Investment	\$370,600	\$459,000	\$383,000
Discounted Annual Costs	<u>572,373</u>	<u>440,113</u>	<u>428,087</u>
Total Present Value	\$942,973	\$899,113	\$811,087

### 3.2.3

#### Conclusions.

- a. Alternatives "B" and "C" have an energy conservation advantage over Alternative "A".
- b. Alternative "C" has an economic advantage over Alternatives "A" and "B".

### 3.2.4

#### Recommendations.

Alternative "B" has the highest initial cost of all three alternatives. Furthermore, the long term savings in operating costs of Alternative "B" are less than the savings of Alternative "C". Consequently, Alternative "B" is not recommended.

Alternatives "A" and "C" are recommended as follows:

- a. Alternative "A" is recommended whenever existing 60/400 Hz motor generator sets are available for reuse at the 400 Hz central generating plant.
- b. At Naval Air Stations where all new equipment is planned, the following are the recommended alternatives based on current and projected cost of equipment and power generation:

Alternative "A" - for minimum first cost

Alternative "C" - for minimum life cycle cost

### 3.2.5 Initial Investment.

#### 3.2.5.1 Alternative "A" - Motor Generator (Low Voltage).

Item No.	Description	Quantity	Unit Cost Installed	Total
1	313 KVA-600V Motor Generator with Step-up Transformer and Primary and Secondary Circuit Breakers	4	\$74,000	\$296,000
2	1000 KVA Transformer, 5KV/480V	2	25,000	50,000
3	200A-3P-4160V Circuit Breaker	2	6,000	12,000
4	1600A-3P-600V Circuit Breaker	2	4,200	12,600
			Total	<u>\$370,600</u>

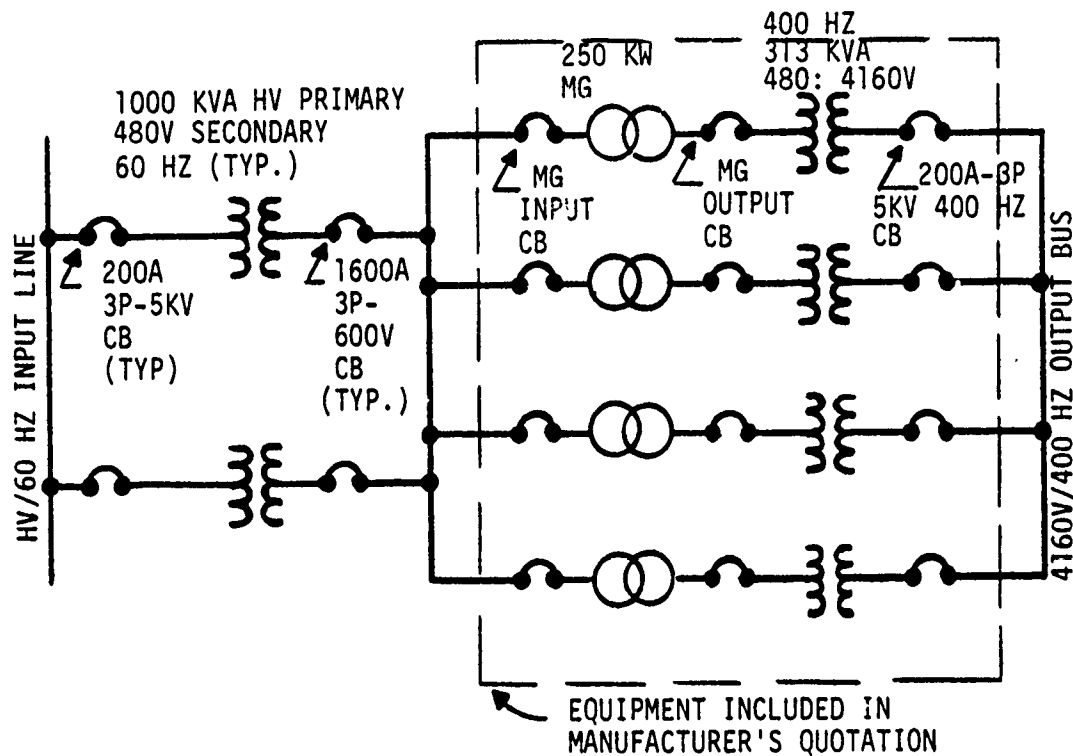
#### 3.2.5.2 Alternative "B" - Motor Generator (High Voltage).

Item No.	Description	Quantity	Unit Cost Installed	Total
1	313 KVA - 4160V Motor Generator with Primary and Secondary Circuit Breaker	4	\$110,000	\$440,000
2	Control Console	1	19,000	<u>19,000</u>
			Total	<u>\$459,000</u>

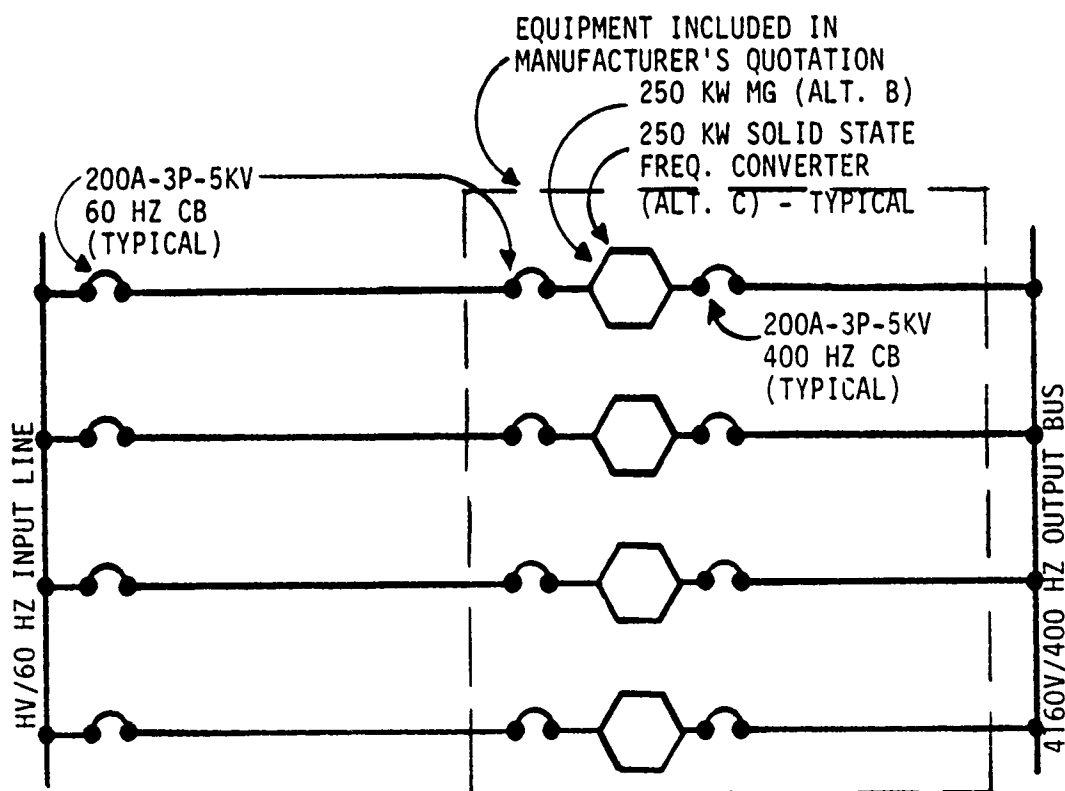
3.2.5.3 Alternative "C" - Solid State (High Voltage).

Item No.	Description	Quantity	Unit Cost Installed	Total
1	313 KVA - 4160V Solid State Frequency Con- verter with Primary and Secondary Circuit Breaker	4	\$91,000	\$364,000
2	Control Console	1	19,000	<u>19,000</u>
			Total	\$383,000

### 3.2.6 ONE-LINE DIAGRAMS - ALTERNATIVES "A", "B" AND "C".



ALTERNATIVE A



ALTERNATIVES B & C

### 3.2.7 Operating Costs. (Refer to Appendix F for backup data).

Operating costs for the three alternatives are tabulated as follows:

	<u>Alternatives</u>		
	<u>"A "</u>	<u>"B "</u>	<u>"C "</u>
(1) Power losses through frequency conversion	149 KW	130 KW	112 KW
(2) Power losses through primary 60 Hz, 4160/480V transformers - 1.5% of 2000 KVA connected capacity	30 KW	-----	-----
(3) Power losses through secondary 400 Hz transformers - 1.0% of 1252 KVA	12 KW	-----	-----
(4) Total power losses	191 KW	130 KW	112 KW
(5) Total KWH @ 8760 Hours per Year	1,673,160 KWH	1,138,800 KWH	981,120 KWH
(6) Total yearly cost at \$0.04 per KWH	<u>\$66,926</u>	<u>\$45,552</u>	<u>\$39,245</u>

### 3.2.8 Maintenance.

Maintenance costs for the three alternatives are based on the following estimated costs:

#### Alternative "A ":

$$\$100/\text{unit}/\text{month} = \$100 \times 4 \times 12 = \$4,800 \text{ per year}$$

#### Alternative "B ":

$$\$200/\text{unit}/\text{month} = \$200 \times 4 \times 12 = \$9,600 \text{ per year}$$

#### Alternative "C ":

$$\$300/\text{unit}/\text{month} = \$300 \times 4 \times 12 = \$14,400 \text{ per year}$$

3.2.9 Discounted Annual Costs.

(Present worth of O and M costs).

3.2.9.1 Operations.

From Table B - Present-Value Table, Appendix D, NAVFAC P-442, the "cumulative uniform series" factor of 7.980 is selected. (Inflation rate is not considered; Discount rate 10 percent annually for 15 years).

3.2.9.2 Maintenance.

From Table B - Present-Value Table, Appendix D, NAVFAC P-442, the "cumulative uniform series" factor of 7.980 is selected. (Inflation rate is not considered; Discount rate 10 percent annually for 15 years).

### 3.2.9.3 Discounted Annual Costs.

(1) Operating Cost:		Alternative "A"	Alternative "B"	Alternative "C"
		$(7.980)(\$66,926) = \$534,069$	$(7.980)(\$45,552) = \$363,505$	$(7.980)(\$39,245) = \$313,175$
(2) Maintenance Cost:				
		$(7.980)(\$4,800) = 38,304$	$(7.980)(\$9,600) = 76,608$	$(7.980)(\$14,400) = 114,912$
(3) Discounted Annual Costs:				
		<u>\$572,373</u>	<u>\$440,113</u>	<u>\$428,087</u>

## SECTION 4

### APPENDIX

- 'A' - List of References
- 'B' - NAS Miramar - Schedule of Existing 400 Hz Motor Generators to be replaced by Centralized 400 Hz Motor Generators under Project P-218
- 'C' - Table - Acquisition Cost of Mobile Units at NAS Miramar
- 'D' - Summary of Fixed and Mobile 400 Hz Power Capacity by Station
- 'E' - Revised Economic Analysis at NAS Miramar to Conform to Recommendations in Section 2
- 'F' - Energy Cost Analysis
- 'G' - Table VIII - Summary of Aircraft Starting and Servicing Electrical Power (400 Hz) Requirements - Page IV-8 of Report No. 3-75 (Volume One of Two Volumes)
- 'H' - Figure 13 - Typical Diversity/Demand Factors for 400 Hz Power to support Aircraft Page 111-13 of Report No. 3-75 (Volume One of Two Volumes)
- 'I' - Technical Proposal for 60/400 Hz, 4160V input, solid-state frequency converter
- 'J' - Conductor Resistance Effects at High Frequencies
- 'K' - Detail of Low Voltage Cable; Table of Typical Characteristics of 600V and 5KV cable
- 'L' - JB & B Letter dated August 11, 1976, with questionnaire and outline specifications. (Revised to include outline specifications for line drop compensators).
- 'M' - Summary of responses to JB & B questionnaire (Appendix 'L') by potential suppliers of 400 Hz equipment

LIST OF REFERENCES

- No. 1      Centralized High Voltage 400 Hz Distribution System: Progress Report - Prepared by ESA - 742: NWESA
- No. 2      Aircraft Ground Support 400 Hz Electrical Power Requirement Evaluation. Report No. 3-73 dated January 1973 - Prepared by ESA-742: NWESA
- No. 3      Page V-(C)-3 of Report No. 3-75 (Volume One of Two Volumes)
- No. 4      NAEC-GSED-86-Appendix C-3M Data from 5 NAS
- No. 5      Progress Report No. 1; June 1976 by JB & B
- No. 6      Progress Report No. 2; July 1976 by JB & B
- No. 7      Questionnaire by JB & B dated 24 June 1976
- No. 8      Letter by JB & B dated 18 June 1976
- No. 9      Letter with attached questionnaire by JB & B dated 11 August 1976
- No. 10     Pages II-4 through II-8 from Report No. 3-75, Volume One of Two Volumes
- No. 11     F-14 Flight Line Servicing/Starting Electrical Power (400 Hz) Requirements Evaluation; First and Final Report. Report No. ST-75R-74 dated 21 June 1974
- No. 12     Report on Electrical Engineering Study of 400 Hz Electric Power at NAS Oceana, Virginia - Report Number ESR #7-74 dated 1 October 1975.

RE: NAS MIRAMAR, CA

Schedule of Existing Individual 400 Hz Motor Generators  
To Be Replaced By Centralized 400 Hz MG's Under  
Project P-218

400 HZ MOTOR GENERATOR SCHEDULE (EXIST)							
Item No.	Qty.	Bldg. No.	KVA.	Output Voltage	Phase	Sheet No.	Manufacturer
A	4	K-215	60	120/208	3	E-4	Inet
	4	K-215	60	120/208	3	E-4	Inet
B	2	K-277	60	120/208	3	E-5	Hollingsworth
	8	K-277	60	115/200	3	E-5	Hollingsworth
	1	K-277	30	120/208	3	E-5	Elect. Prod.
	2	Wells	60	120/208	3	E-5	Inet.
E	2	402	30	120/208	3	E-14	Elect. Prod.
	3	402	60	115/200	3	E-14	Inet
	2	402	60	115/200	3	E-14	McDonnell
F	1	456	30	115/200	3	E-14	Elect. Prod.
	1	456	75	115/200	3	E-14	Elect. Prod.
G	2	470	50	120/208	3	E-7	Kato
	3	470	60	120/208	3	E-7	Hollingsworth
	3	Apron	60	115/200	3	E-7	Inet
H	3	490	150	115/200	3	E-20	Amer. Elect.
	2	490	125	120/208	3	E-20	Inet
J	2	500	62.5	120/208	3	E-6	Inet

A P P E N D I X 'B'

Sheet No. 2 of 2

## 400 HZ MOTOR GENERATOR SCHEDULE (EXIST)

Item No.	Qty.	Bldg. No.	KVA	Output Voltage	Phase	Sheet No.	Manufacturer
K	2	K-515	150	120/208	3	E-21	Amer. Elect.
	1	K-515	125	115/200	3	E-21	Amer. Elect.
	2	K-515	62.5	115/200	3	E-21	Amer. Elect.
	1	K-515	100	115/200	3	E-21	Kato
L	1	419 Aircraft Parking Apron	60	200	3	E-18	Kato
M	2	K-940	75	120/208	3	E-18	Inet

SUMMARY

<u>Qty.</u>	<u>KVA-EA</u>	<u>KVA-TOTAL</u>
4	30	120
2	50	100
36	60	2,160
3	75	225
1	100	100
3	125	375
5	150	750
54	70.9	3,830 KVA

(KVA per)

(Unit)

(Average)

NOTE: Data obtained from NAVFAC DWG. No. 6076944, Sheet 5 dated 5-14-76  
Code Ident. No. 80091

TABLE      - ACQUISITION COST OF  
                              MOBILE UNITS

NC-8A:	40,000
NC-10:	35,000
NC-10C:	40,000
MMG-1A:	20,000

TOTAL:                      \$ 135,000 divided by 4 = \$33,750 average cost per unit

Average Unit = 60 KW/75KVA

Cost per KW - \$33,750 divided by 60 KW = \$562/KW

SUMMARY OF FIXED AND MOBILE  
400 HERTZ POWER CAPACITY BY STATION

(Per Table, Page A-2 of Report 3-73)

STATION	INSTALLED EQUIPMENT		MOBILE EQUIPMENT		STATION TOTAL		PERCENT OF TOTAL CAPACITY		RATIO OF FIXED TO MOBILE EQUIPMENT
	No. Gen.	Capacity (KVA)	No. Gen.	Capacity (KVA)	No. Gen.	Capacity (KVA)	Fixed	Mobile	
ALAMEDA	7	270	61	3315	68	3585	.08	.92	270:3315 = 8%
CECIL FIELD	11	660	44	1785	55	2445	.27	.73	660:1785 = 37%
EL TORO - SANTA ANA	49	2580	109	7281	158	9861	.26	.74	2580:7281 = 35%
JACKSONVILLE	13	780	32	1630	45	2410	.32	.68	780:1630 = 48%
LEMOORE	26	1402	96	4965	122	6367	.22	.78	1402:4965 = 28%
MIRAMAR	57	3910	92	6480	149	10390	.38	.62	3910:6480 = 60%
MOFFET	14	519	35	3015	49	3534	.15	.85	519:3015 = 17%
OCEANA	25	2640	62	3285	87	5925	.45	.55	2640:3285 = 80%
WHIDBEY	20	1737	83	3690	103	5427	.32	.68	1737:3690 = 47%
TOTALS	222	14498	614	35446	836	49944			14498:35446= 41%

A P P E N D I X 'D'

REVISED ECONOMIC ANALYSIS AT NAS MIRAMAR TO CONFIRM TO RECOMMENDATIONS  
IN SECTION NO. 2

\$1,102,000 - Per Ref. No.: 14, Project No. P-218  
421,000 - Additional Equipment as detailed below \*\*  
 \$1,523,000 - Total

\*\* Furnish and install the following equipment to conform to requirements of Section 2.

\$100,000 - Two 250 KW/312 KVA MG's  
 15,000 - One 60 Hz 750 KVA 4160:480/277 V. Stepdown Transformer.  
 20,000 - One 400 Hz 600 KVA 480/277: 4160V Stepup Transformer.  
 15,000 - Switchgear associated with above Transformer and MG's  
 169,000 - Line drop Compensators: 47 @ 60 KVA (average rating) = 2820 KVA.

---

319,200 - Subtotal  
15,960 - + 5% Contingency  
 335,160 -  
80,329 + 18% Escalation thru March 1978.  
 395,489 -  
25,244 - 94 (+6%) Supervision, Inspection, etc.  
 420,733 - Total

9. Total cost of power for 400 Hz power generation including loss plus useful power is based on expected power costs of .04 per KW hour.  $3,620,000 \times .04 = \$145,065.00$  per year.

1.2 Plan A  
Continued

Estimated Cost of Fuel Consumption for  
Mobile 400 Hz Engine Generator Sets

The estimate of power consumption in the form of fuel for operation of engine generator sets is difficult to arrive at for a number of reasons.

The use of the mobile engine generator sets is where no stationary 400 Hz power is available, such as locations on the flight line. The use is probably of short duration for most of the engine generator sets, as contrasted to the nearly continuous operation of the motor generator sets. Further, fuel is consumed not only in generating 400 Hz power, but also in movement to of engine generator sets to locations where 400 Hz power is required. All of the assumptions used to arrive at conclusions of fuel consumption, power consumption and operating costs are set forth as follows.

1. Total 400 Hz power capacity for the summation of all engine generator sets KVA ratings at Miramar NAS is 6480 KVA.
2. It is assumed that 70% of all of these sets are in operational condition, and that 30% of the total are down for maintenance or repair on an average basis. Thus, the available capacity is  $.7 \times 6480 = 4520$  KVA.
3. Fuel costs are estimated on the following basis:
  - a. Diesel fuel cost at \$.40 per gallon.  
  
At 6.7 lbs per gallon, this equals  $0.40/6.7 = \$.06$  per lb. of fuel.
  - b. 5% of the fuel consumed is for movement of the mobile power plants from one location to another. Thus, 95% is available for power generation.
  - c. Generator efficiency is estimated at 85%.
  - d. Engine efficiency at full rated load of the generator requires .65 lbs. <sup>4</sup> per horsepower hour, as the specific fuel consumption.
  - e. Fuel consumption per KW hour is then,  $KW/HP \times \text{specific fuel consumption} \times 1/\text{Efficiency} = 1.34 \times .6 \times (1/.95 \times .85) = 1.08$  lbs/KW hr.
  - f. 1.08 lb of fuel per KW hour with fuel cost of \$.06 per lb. the cost per KW hour at full load would be  $1.08 \times .06 = \$.065$ .
4. The average load is estimated on the basis of operation of the sets for 12 hours per day with 40% of the available engine generator sets on-line.

5. It is estimated that the average load will be 5.8% of the one-line power.  
 $.058 \times 900 = 52 \text{ KVA average load.}$
6. The peak load is estimated to be 35% of the available power.  $900 \times .35 = 316 \text{ KVA.}$
7. Fuel consumption at no load is estimated to be 30% of full load fuel consumption and hence cost of fuel will be 30% of the full load fuel cost.  
 $.065 \times .3 = \$.02 \text{ per KVA Hour of average on-line capacity.}$   
Cost per hour at no load is then  $.02 \times 900 = \$18.00 \text{ per hour.}$
8. Fuel cost for useful power is  $(0.065 - .02) \times 52 = \$2.34 \text{ per hour.}$
9. Total fuel cost of operation is then fuel cost for power loss plus fuel cost for useful power.  $\$18.00 + \$2.34 = \$20.34 \text{ per hour.}$
10. Yearly cost will be  $\$20.34 \text{ per hour} \times 8760 \text{ hours} = \$178,176.00 \text{ for total power of } 8760 \times 52 = 455,520 \text{ KW hours. Cost per KW hour} = \$.39.$

## 2.0 Central Power System (Plan B)

1. The peak power capacity and the average power consumed are assumed to be unchanged from present demands.
2. Peak demand is then  $460 + 315 = 775$  KVA. Based on 312 KVA modules, the total number of on-line units must be 3 with capacity of 936 KVA. A fourth unit is required for redundancy.
3. No. of units is based on replacement of all of the present stationary equipment and 75% of all engine generator sets.
4. No. of on-line transformers are assumed to be equal in total power capacity to the combination of mobile and stationary equipment. Total is  $3064 + 5184 = 8248$ .
5. No load power losses in Item #4 are 1% of capacity of system = 82.48 KW.
6. The 936 KVA of spinning generators will have a no load loss of 6% of their rating =  $.06 \times 936 = 56$  KW.
7. 25% of the mobile equipment will be retained under Plan B. It will be required to supply 25% of the average previous load which was 52 KW.  
 $.25 \times 52 = 13$  KW average load retained.  
  
75% of the mobile equipment load will be transferred to the new central station.  $.75 \times 52 = 39$  KW average load transferred.
8. The central power station load will now become the total of the stationary equipment to average load of 92 KW plus the above 39 KW, or a total of 131 KW.
9. The motor generators will have an additional power loss of 8% of the average load. Average load is  $39 \text{ KW} + 92 \text{ KW} = 131 \text{ KW}$ . Additional losses are  $131 \times .08 = 10.5$  KW.
10. Total power consumed is total of used power plus total losses. Used power equals 131 KW. Losses =  $56 + 10.5 + 82.48 = 149$  KW. Total = 280 KW.
11. Yearly power consumption is  $280 \text{ KW} \times 8760 \text{ hours} = 2,452,800 \text{ KW hours} \times \$0.04 \text{ per KWH} = \$98,112$ .
12. The cost of fuel for operating the remaining engine generator sets is assumed to be at the original cost rate of \$.39 per KW hour average.

Power generated is  $13 \times 8760 = 113,880$  KW. Annual cost of this power is  $.39 \times 113,880 = \$44,413.00$ . Annual power and fuel costs for Plan B are then  $44,413 + 98,112 = \$142,525.00$ .

13. Annual energy savings are as follows:

$$\$145,065 + 178,176 = \$323,241 - 142,525 = \$180,715.00 \text{ per year.}$$

\$145,065 is cost of energy for stationary power plant operation in Plan A.

\$178,176 is cost of fuel for engine generator set operation in Plan A.

\$142,525 is cost of energy plus fuel for Plan B.

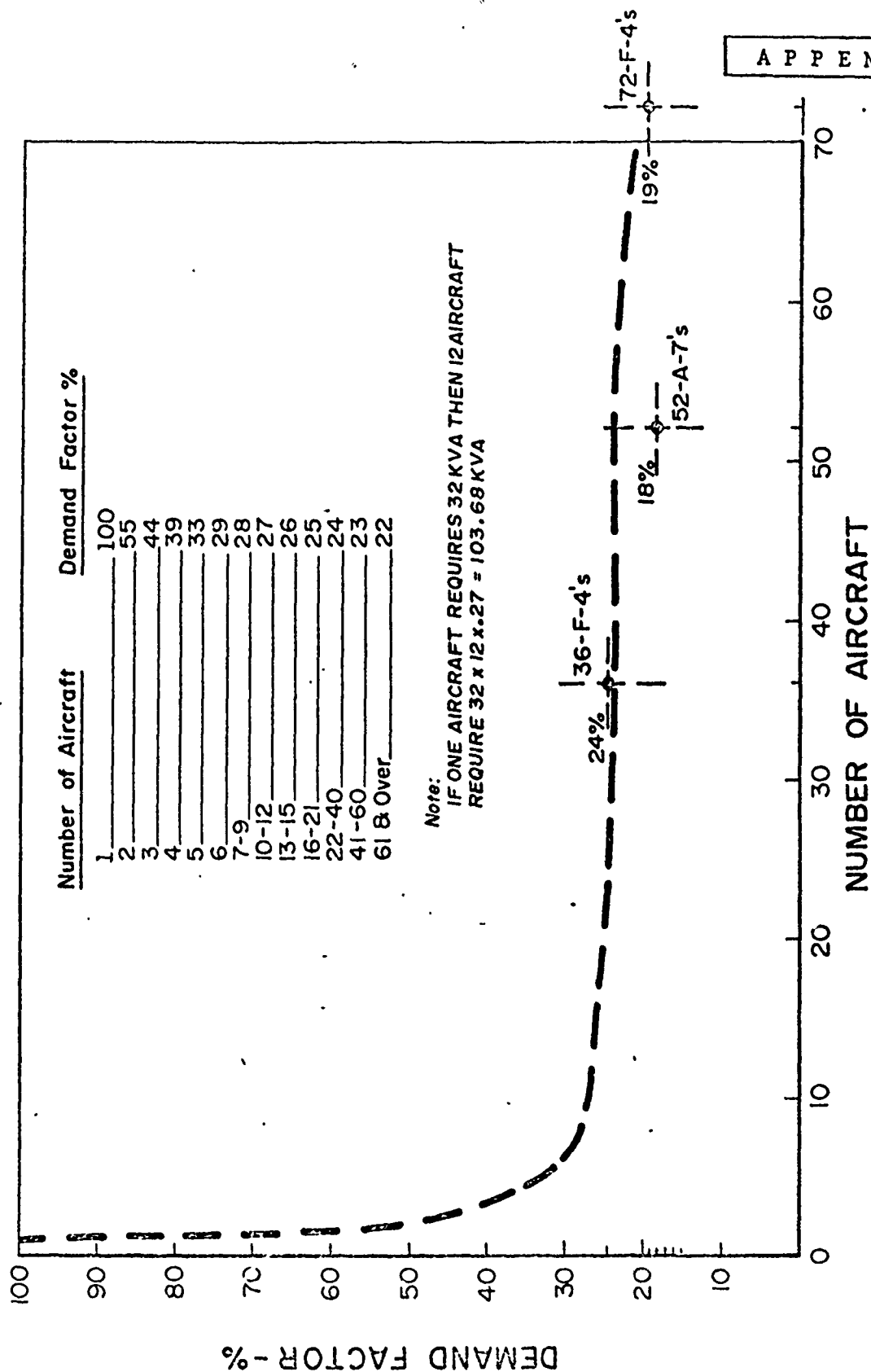
\$180,715 per year is the net savings of fuel and energy costs for the central 400 Hz power system.

TABLE VIII SUMMARY OF AIRCRAFT STARTING AND SERVICING ELECTRICAL POWER (400 Hz) REQUIREMENTS

Aircraft Type	Average Measured Load Power (KVA)	Maximum Measured Load Power (KVA)	Maximum Calculated Load For Servicing Power (KVA)
A-3B	3.91	6.04	16.4
A-4C	1.95	2.68	5.4
A-6A	4.23	8.65	20.0
EA-6B*	16.50	17.94	--
A-7E	4.39	4.48	9.0
E-2C*	50.00	80.00	<del>70.0</del> 90.0
F-4J	5.46	10.35	20.0
F-8K	2.94	5.19	8.7
F-14A#	17.30	25.60	64.0
P-3C	17.50	36.30	60.0
S-2E	2.44	3.56	15.0
S-3A*	30.00	32.00	60.0
CH-53A	3.62	10.35	40.0
HH-3D	5.36	16.50	15.0

\* Not included in the Summary of Aircraft Starting and Serving Electrical Power (400 Hz) Requirements as presented in NATC Report No. ST-75R-74.

# Values changed to this as a result of NATC Report No. ST-75R-74.



**Figure 13** - Typical Diversity / Demand Factors  
For 400 Hz Power To Support Aircraft

**APPENDIX 'I'**

**TECHNICAL PROPOSAL  
FOR  
60/400 HZ SOLID-STATE  
FREQUENCY CONVERTER**

**Prepared for**

**Jaros, Baum and Bolles  
1052 West 6th Street  
Los Angeles, California 90017**

**TELEDYNE INET  
711 WEST KNOX STREET  
GARDENA, CALIFORNIA 90248  
Phone: (213) 327-0913 - Telex: 67-7228**

**19 NOVEMBER 1976**

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Photograph - 75 KVA, 60/400 Hz Frequency Converter

Photograph - 75 KVA Converter with Logic Drawer

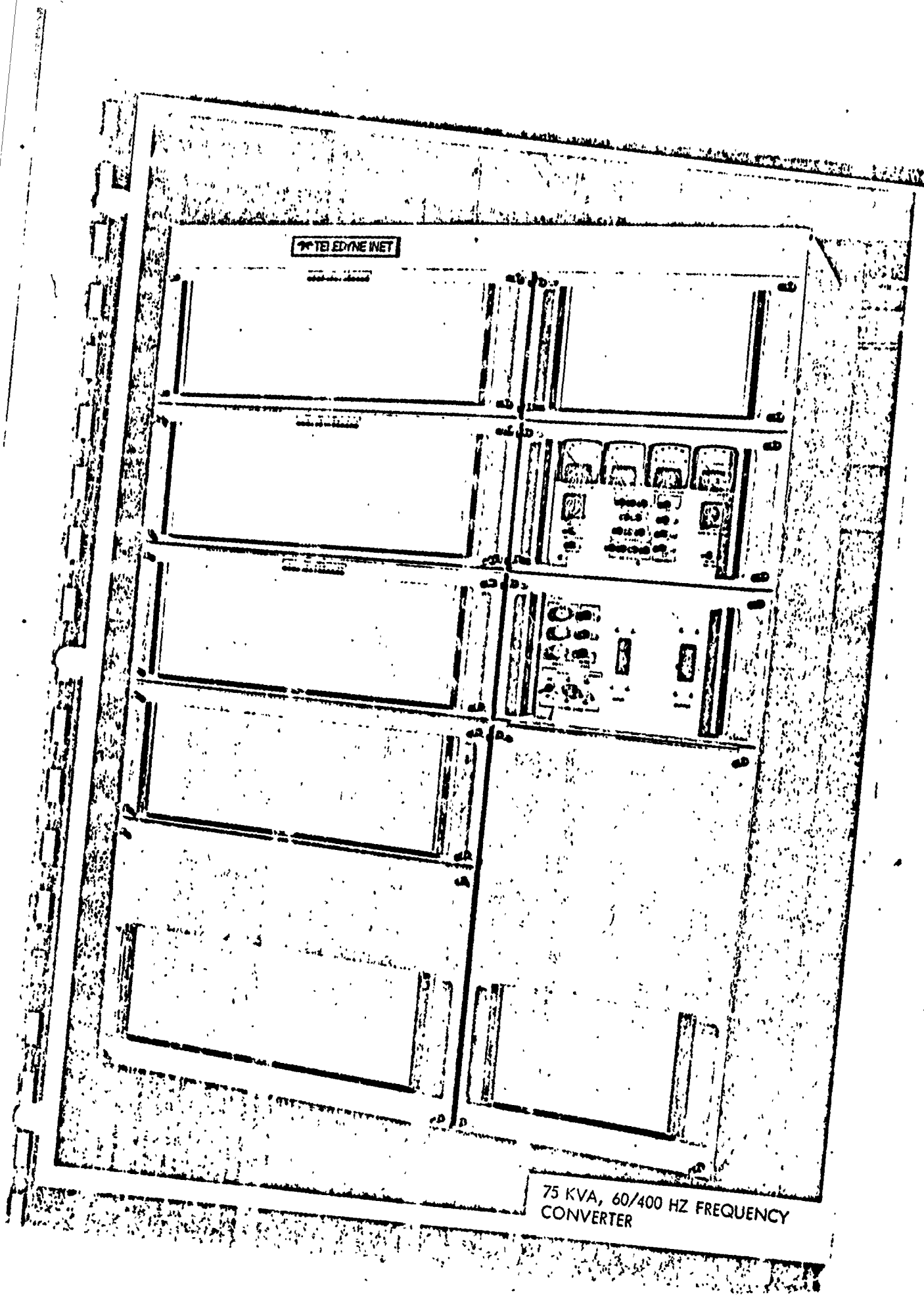
Photograph - 75 KVA Converter with Full Bridge Drawer

Catalog Sheet - Series 75/415 Hz Uninterruptible Power Systems

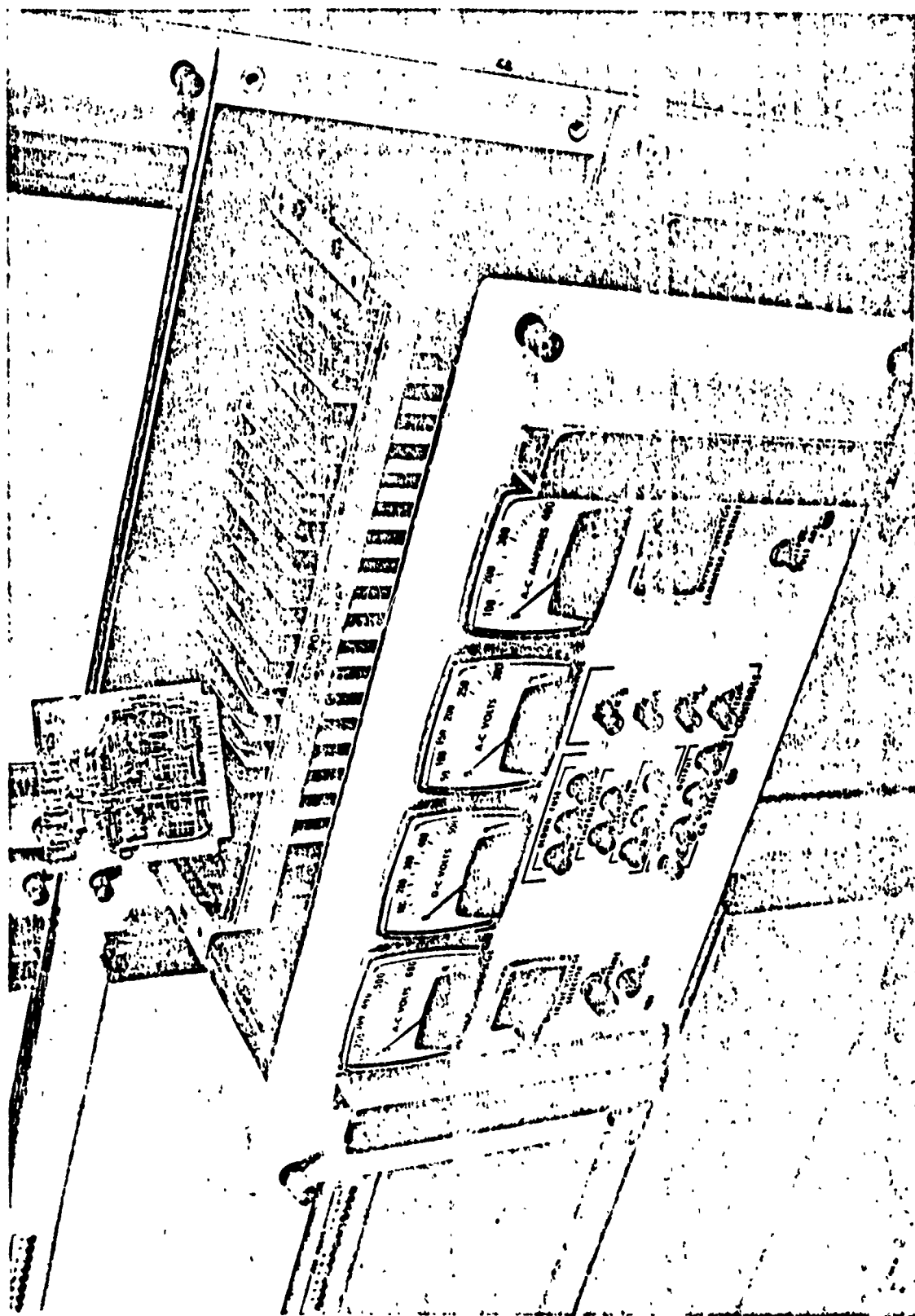
Catalog Sheet - Series 210/415 Hz Uninterruptible Power Systems

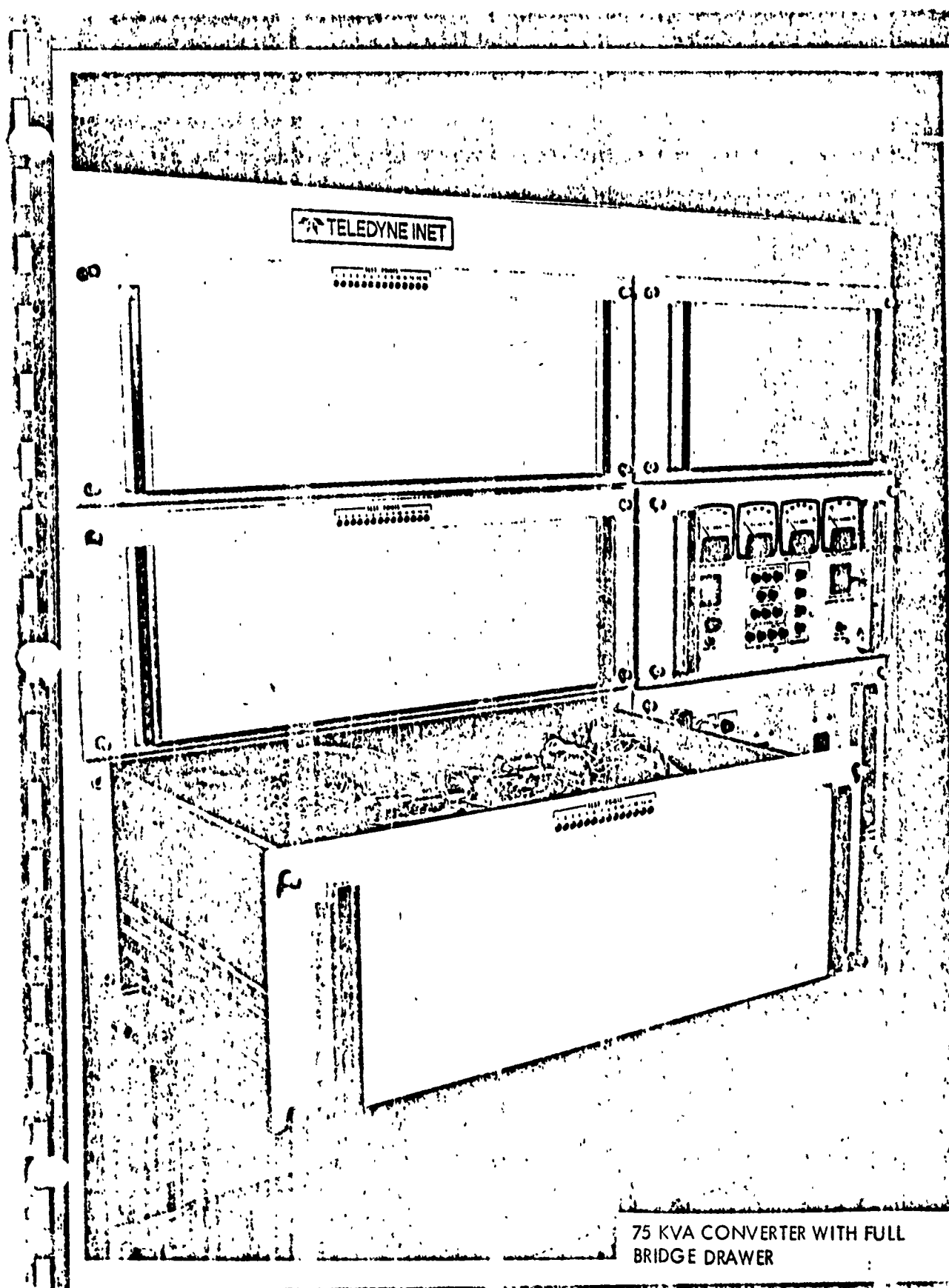
Catalog Sheet - Series 313 KVA Uninterruptible Power Systems

Proposal for 1565 KVA, 60/400 Hz Solid-State Frequency Changer Power System



75 KVA CONVERTER WITH LOGIC  
DRAWER

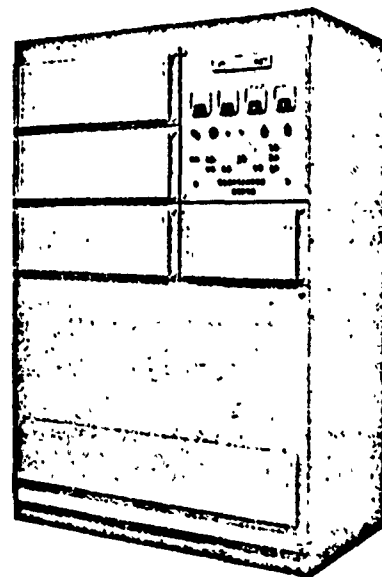




# TELEDYNE INET Series 75/415 Hz

## Uninterruptible Power Systems

Teledyne Inet's 415 Hz Uninterruptible Power Systems provide precisely conditioned power for your critical data/communications requirements. The heart of this Series is the 75 KVA 415 Hz Frequency Converter which may be used singly or in parallel for system redundancy or increased power capacity. In addition to the frequency converter(s), a complete UPS system includes associated batteries and specified options.



**75 KVA/415 Hz Module**

### ELECTRICAL SPECIFICATIONS

#### Input

Voltage	208 or 480, 3-phase, 3 or 4 wire, $\pm 10\%$
Frequency	60 Hz, $\pm 5\%$
Power Factor	0.85 at full load
Harmonic Feedback	10% maximum at full load
Power Walk-in	15 seconds to full load
Current Limit	125% of full load

#### Output

Rating	75 KVA 67.5 KW
Efficiency	86% at full load
Voltage Regulation	$\pm 1\%$
Phase, Angle	$120^\circ \pm 1^\circ$ balanced load
Harmonic Voltage	3% maximum single 5% maximum total R.M.S.
Frequency, nominal	415 Hz $\pm 0.1\%$ (400 Hz also available)
Frequency Regulation	$\pm 0.1$ Hz
Overload Capacity	125% for 15 minutes 150% for 2 minutes 500% for first cycle declining to 150% until fault clears
Short Circuit	

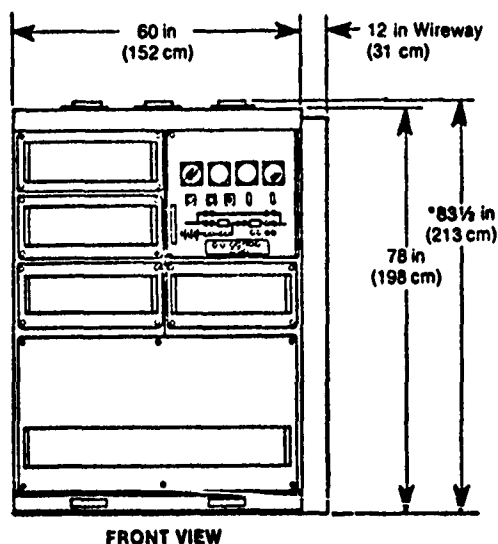
#### Voltage Transient Response

$\pm 8\%$  with 100 ms maximum recovery time for:

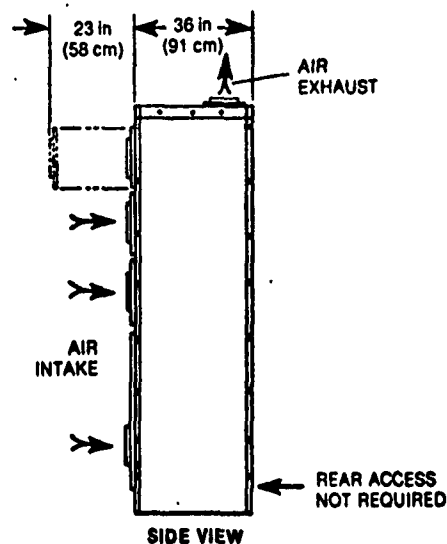
- (a) 50% load step
- (b) Loss or return of AC input power
- (c) Adding or dropping one converter of parallel group

### STANDARD FEATURES

- Output voltmeter and ammeter
- Battery voltmeter and ammeter
- System fault alarms
- Line drop compensation, 0 - 5%
- Rear access not required



\*Exhaust fans removable for shipping.



## PHYSICAL SPECIFICATIONS

Dimensions	72"W x 83 1/2"H x 36"D (183 cm x 213 cm x 91 cm)
Weight	4,200 lbs. (1,909 kg)
Ventilation	Forced air (redundant blowers)
Cable Entry	Top, bottom or rear via wireway
Acoustic Noise	70 db at 5 ft. (1.5 m)

## ENVIRONMENTAL SPECIFICATIONS

Operating Temperature Range	
Recommended	20°C to 30°C
Maximum	0°C to 50°C
Nonoperating Temperature Range	
0°C to 70°C	
Relative Humidity	0 to 95 percent
Altitude	0 to 5000 ft. (0 to 1524 m)
Heat Rejection	625 BTU/min (158 kcal/min)

## BATTERY SPECIFICATIONS

Type	Lead calcium (clear, shock absorbing, heat resistant plastic case)
Number of cells for	
(a) 1.75 VDC end point	120 cells
(b) 1.65 VDC end point	124 cells
DC Voltage range	210-300 VDC
Maximum full load battery current	318 amps DC

BATTERY AND RACK DATA		
Support Time	9 Min.	15 Min.
Cell Number	IN180-4	IN170-2
Total Weight	5,800 lbs. (2,645 kg)	8,400 lbs. (3,818 kg)
Installed Size and Quantity	Two 3-tier 8' racks 18"D x 74"H (46 cm x 188 cm)	Two 2-tier 8' racks 20"D x 53"H (51 cm x 135 cm)

## OPTIONS AND SERVICES

- Central mimic bus/control panel for parallel system
- Remote monitor or alarm panel
- Shock protected battery rack
- Battery disconnect switch
- Test console
- Turnkey Contracts
- Leasing Arrangements
- Maintenance Agreements
- Installation Supervision
- Site Testing

(Refer to individual Bulletins for details on above Options and Services)

All specifications subject to verification for each order.

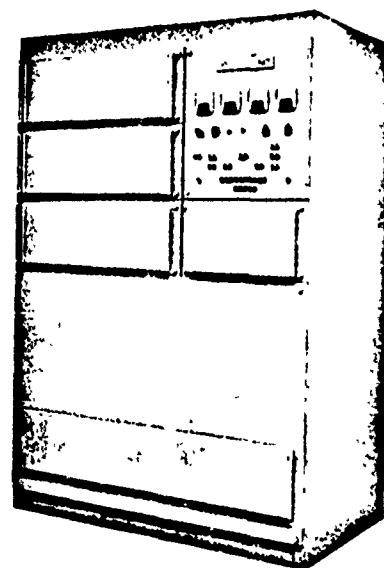
**TELEDYNE INET**

711 West Knox Street • Gardena, California 90248 • Telephone: (213) 327-0913 • Telex: 67-7228

# TELEDYNE INET Series 210/415 Hz

## Uninterruptible Power Systems

Teledyne Inet's 415 Hz Uninterruptible Power Systems provide precisely conditioned power for your critical data/communications requirements. The heart of this Series is the 210 KVA 415 Hz Frequency Converter which may be used singly or in parallel for system redundancy or increased power capacity. In addition to the frequency converter(s), a complete UPS system includes associated batteries and specified options.



**210 KVA/415 Hz Module**

### ELECTRICAL SPECIFICATIONS

#### Input

Voltage	208 or 480, 3-phase 3 or 4 wire, $\pm 10\%$
Frequency	60 Hz, $\pm 5\%$
Power Factor	0.85 at full load
Harmonic Feedback	10% maximum at full load
Power Walk-In	15 sec. to full load
Current Limit	125% of full load

#### Voltage Transient Response

$\pm 8\%$  with 100 ms maximum recovery time for:

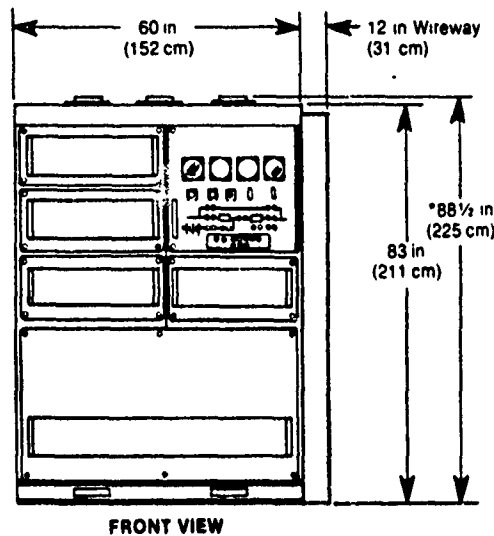
- (a) 50% load step
- (b) Loss or return of AC input power
- (c) Adding or dropping one converter of parallel group

#### Output

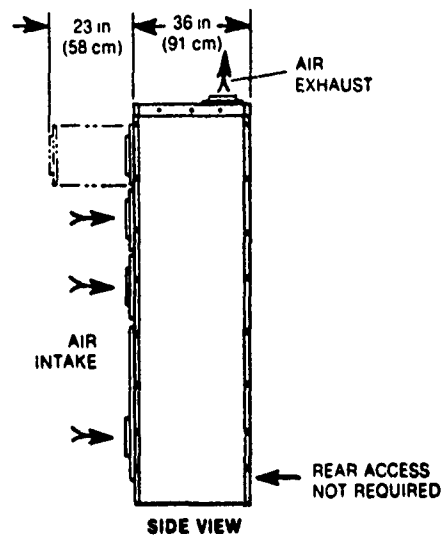
Rating	210 KVA, 0.8 PF 187 KVA, 0.9 PF 168 KW, 1.0 PF 88% at full load
Efficiency	$\pm 1\%$
Voltage Regulation	$120^\circ \pm 1^\circ$ balanced load
Phase Angle	3% maximum single
Harmonic Voltage	5% maximum total R.M.S. 415 Hz $\pm 0.1\%$ (400 Hz also available)
Frequency, nominal	$\pm 0.1$ Hz
Frequency Regulation	$\pm 0.1$ Hz
Overload Capacity	125% for 15 minutes 150% for 2 minutes
Short Circuit	500% for first cycle declining to 150% until fault clears

### STANDARD FEATURES

- Output voltmeter and ammeter
- Battery voltmeter and ammeter
- System fault alarms
- Line drop compensation, 0 - 5%
- Rear access not required



\*Exhaust fans removable for shipping.



## PHYSICAL SPECIFICATIONS

Dimensions	72"W x 88 1/2"H x 36"D (183 cm x 225 cm x 91 cm)
Weight	6,250 lbs. (2,840 kg)
Ventilation	Forced air (redundant blowers)
Cable Entry	Top, bottom or rear via wireway
Acoustic Noise	78 db at 5 ft. (1.5 m)

## ENVIRONMENTAL SPECIFICATIONS

Operating Temperature Range	
Recommended	20°C to 30°C
Maximum	0°C to 50°C
Nonoperating Temperature Range	0°C to 70°C
Relative Humidity	0 to 95 percent
Altitude	0 to 5000 ft. (0 to 1524 m)
Heat Rejection	1303 BTU/min (328 kcal/min)

## BATTERY SPECIFICATIONS

Type	Lead calcium (clear, shock absorbing, heat resistant plastic case)
------	--

Number of cells for	
(a) 1.75 VDC end point	172 cells
(b) 1.65 VDC end point	180 cells
DC Voltage Range	300-432 VDC
Maximum full load battery current	613 amps DC

BATTERY AND RACK DATA		
Support Time	7 Min	16 Min.
Cell Number	IN170-3	IN170-4
Total Weight	15,000 lbs. (6810 kg)	19,125 lbs. (8683 kg)
Installed Size and Quantity	Three 2-tier 7' racks 20"D x 53"H (51 cm x 135 cm)	Three 2-tier 10' racks 20"D x 53"H (51 cm x 135 cm)

## OPTIONS AND SERVICES

- Central mimic bus/control panel for parallel system
- Remote monitor or alarm panel
- Shock protected battery rack
- Battery disconnect switch
- Test console
- Turnkey Contracts
- Leasing Arrangements
- Maintenance Agreements
- Installation Supervision
- Site Testing

(Refer to individual Bulletins for details on above Options and Services)

All specifications subject to verification for each order.

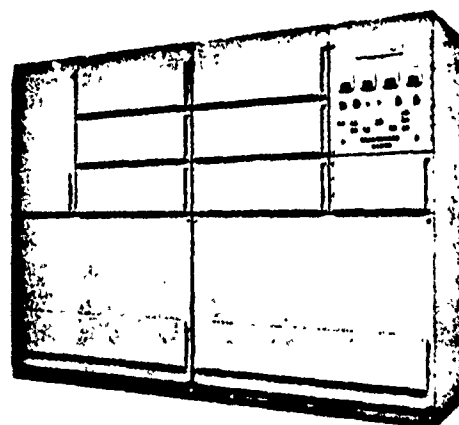
**TELEDYNE INET**

711 West Knox Street • Gardena, California 90248 • Telephone: (213) 327-0913 • Telex: 67-7228

# TELEDYNE INET Series 313

## Uninterruptible Power Systems

Teledyne Inet's Uninterruptible Power Systems provide precisely conditioned power for your critical data communications requirements at a remarkable cost-saving efficiency of 90%. The heart of this Series is the 313 KVA power converter which may be used singly or in parallel for system redundancy or increased power capacity. In addition to the power converter(s), a complete UPS system includes associated batteries and specified options.



**313 KVA Module**

### ELECTRICAL SPECIFICATIONS

#### Input

Voltage	208 or 480, 3-phase, 3 or 4 wire, $\pm 10\%$
Frequency	60 Hz, $\pm 5\%$
Power Factor	0.85 at full load
Harmonic Feedback	10% maximum at full load
Power Walk-in	15 seconds to full load
Current Limit	125% of full load

#### Output

Rating	313 KVA, 0.8 PF 280 KVA, 0.9 PF 250 KW, 1.0 PF
Efficiency	90% at full load
Voltage Regulation	$\pm 1\%$
Phase Angle	$120^\circ \pm 1^\circ$ balanced load
Harmonic Voltage	3% maximum single 5% maximum total R.M.S.
Frequency, nominal	60 Hz
Frequency Tracking Range	$\pm 0.5$ Hz
Frequency Regulation	$\pm 0.1$ Hz
Overload Capacity	125% for 15 minutes 150% for 2 minutes
Short Circuit	500% for first cycle declining to 150% until fault clears

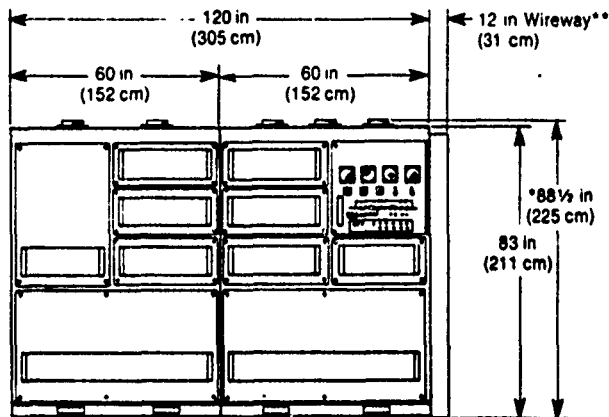
#### Voltage Transient Response

$\pm 8\%$  with 100 ms maximum recovery time for:

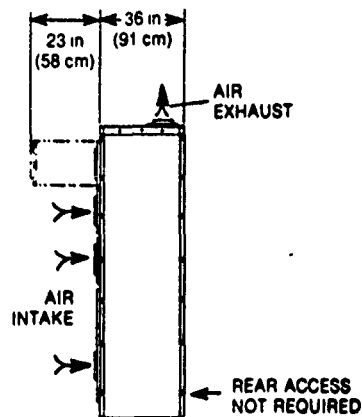
- (a) 50% load step
- (b) Loss or return of AC input power
- (c) Manual or automatic load transfer between UPS and bypass line
- (d) Clearing a load branch fuse or breaker rated up to 10% of UPS KW rating
- (e) Adding or dropping one converter of parallel group

### STANDARD FEATURES

- Output voltmeter and ammeter
- Battery voltmeter and ammeter
- System fault alarms
- Line drop compensation, 0 - 5%
- Rear access not required



FRONT VIEW



SIDE VIEW

\*Exhaust fans removable for shipping.  
 \*\*Wireway replaced by 36"W cubicle to accommodate optional switchgear complement (refer to Switchgear Bulletin 1016).

Note: Converter may be shipped as one unit or in separate sections as shown.

## PHYSICAL SPECIFICATIONS

Dimensions	132"W x 88 1/2"H x 36"D (335 cm x 225 cm x 91 cm)
Weight	13,500 lbs. (6,136 kg)
Ventilation	Forced air (redundant blowers)
Cable Entry	Top, bottom or rear via wireway
Acoustic Noise	75 db at 5 ft. (1.5 m)

## ENVIRONMENTAL SPECIFICATIONS

Operating Temperature Range	
Recommended	20°C to 30°C
Maximum	0°C to 50°C
Nonoperating Temperature Range	0°C to 70°C
Relative Humidity	0 to 95 percent
Altitude	0 to 5000 ft. (0 to 1524 m)
Heat Rejection	1580 BTU/min (398 kcal/min)

## BATTERY SPECIFICATIONS

Type	Lead calcium (clear, shock absorbing, heat resistant plastic case)
Number of cells for	
(a) 1.75 VDC end point	240 cells
(b) 1.65 VDC end point	252 cells
DC Voltage range	420-590 VDC
Maximum full load battery current	645 amps DC

## OPTIONS AND SERVICES

- Central mimic bus/control panel for parallel system
- Switchgear
- Manual or automatic synchronous bypass
- Static bypass switch
- Remote monitor or alarm panel
- Shock protected battery rack
- Battery disconnect switch
- Test console
- Turnkey Contracts
- Leasing Arrangements
- Maintenance Agreements
- Installation Supervision
- Site Testing

(Refer to individual Bulletins for details on above Options and Services)

All specifications subject to verification for each order.

BATTERY AND RACK DATA		
Support Time	6 Min.	18 Min.
Cell Number	IN170-3	IN170-4
Total Weight	20,300 lbs (9227 kg)	23,400 lbs. (10,636 kg)
Installed Size and Quantity	Four 2-tier 8' racks 20"D x 53"H (51 cm x 135 cm)	Four 2-tier 11' racks 20"D x 53"H (51 cm x 135 cm)

**TELEDYNE INET**

711 West Knox Street • Gardena, California 90248 • Telephone: (213) 327-0913 • Telex: 67-7228

FREQUENCY CHANGER, SOLID STATE TYPE

60/400 HZ CONVERTER POWER SYSTEM, 1565 KVA, 0.8 PF.

## 1.0 SCOPE

This proposal describes a 60/400 Hz Solid State Frequency Converter power system. The system is made up of 313 KVA, 0.8 p.f. power converter modules (PCM), which are parallelable under load. The power system can start with two PCM units, with a beginning rating of 313 KVA, 250KW. Either of the two units can supply full rated 400 Hz AC power, and the second PCM unit is redundant. For every PCM that is added, the system power capacity is increased by 300KW, thus a three PCM system will have 2 x 313 KVA of power capacity or 626 KVA of rated power. A six module system will have five times 313 KVA or 1565 KVA of power capacity of 0.8p.f. or 1250KW total. There is always at least one PCM more available than the maximum rated load would require.

Teledyne Inet is the principal supplier of 400 Hz solid state converters in the world. The company has supplied 187.5 KVA solid state 60 to 400 Hz frequency converters to the U.S. Navy for several years. We are now supplying these units against a back log of over 150 units, scheduled over the next five years. They are used also by the Dutch Navy.

In addition to the military 60/400 Hz frequency converters, Teledyne Inet has supplied over 50 frequency changers to computer customers, where the units are used to power IBM 370 series control data processor units (PCUs). Social Security computers, HEW computers, CIA computers, and many others are operating from these 400 Hz converters; rated 75 KVA. The operational record has been excellent, with very few failures.

Inet is now manufacturing four 210 KVA 60/400 Hz converters for the U. S. Air Force at Warner Robbins Air Force Base.

These 400 Hz converters are all simple modifications of the Teledyne Inet 60 Hz solid state Uninterruptible Power Systems, which the company has been manufacturing for twelve years. Thus the long experience and reliability developed in this 60 Hz equipment has benefitted the design of the 60/400 Hz converters.

It will be observed that the maintainability of the equipment is excellent. Most of the active components are mounted in drawers, which pull out for maintenance. When a drawer is pulled out, there is no disconnection of the cable, and controls, which are arranged to follow the drawers.

Pictures illustrate the equipment with drawers in the withdrawn position. Pictures and catalog sheets are included to illustrate typical equipment. These include.

- a. Catalog sheet of 75KVA converter 60/415 Hz, Bulletin #1015/1-76
- b. Catalog sheet of 210 KVA converter 60/415 Hz, Bulletin #1021/8-76
- c. Catalog sheet of 313 KVA 60 Hz converter, Bulletin #1010/1-76
- d. Picture 75 KVA converter, drawers out.

The frequency converters are not harmed by being subjected to short circuits. Current is limited to approximately 200% of normal full rated current when a continuous short circuit is applied.

## **2.0 TECHNICAL DESCRIPTION**

Each module contains a rectifier to convert 60 Hz AC input power to regulated DC power and an inverter to convert the DC power to 400 Hz AC. Each module also includes all logic and controls so it can operate independently of all other PCM units. The output of each PCM connects through a circuit breaker to the common 400 Hz 3 phase power bus.

Because there is a full isolation power transformer on both the input and the output of the PCM, the input and output voltage can be whatever is required. For example, both the 60 Hz input and the 400 Hz output voltage can be 4160VAC, or whatever voltage is required or convenient. The PCMs are synchronized with each other for parallel operation. Each PCM on line, shares the load equally with other on-line PCM units. If any PCM unit fails, it automatically disconnects from the input and output power buses, with only minimal voltage transients, while the other on-line PCM units pick up and shares the additional load. When a PCM unit fails, both the input and output circuit breakers associated with each PCM are caused to open automatically.

Refer to the Inet catalog sheet describing the 60 Hz 313 KVA power converter module. The size of the 400 Hz will be identical. Performance is nearly the same as the 60 Hz units except for the operational frequency of the Invertor section. System characteristics are listed in table 2-2.

Switchgear is normally provided by Teledyne Inet as a part of the 400 Hz power system so that circuit breakers and controls are coordinated with the PCM equipment.

## 2.2 Frequency Converter Operation.

### 2.2.1 Control Power. Refer to Figure 2-2, a simplified one-line block diagram of the Frequency Converter.

Control power connects from the input 60 Hz mains through the control logic switch SI which is located on the switchgear drawer. Control logic switch SI has three positions, which are: "OFF", "Maintenance" and "Operate". When the switch is in the "OFF" position, all power to the controls and logic are disconnected. A connection is then present to energize the shunt-trip mechanism on the AC input power circuit breaker and the output AC power circuit breaker. With the control switch in the "Maintenance" position, power is applied to all logic and control functions.

The main DC power of the converter is supplied with 24 VDC. This permits a complete checkout of logic and functional control without applications of voltages dangerous to maintenance service personnel. In the "Maintenance" position of the switch, the shunt-trip circuit of the input power and output power circuit breakers remain activated so that closure of these circuit breakers is prevented.

When the controls switch is rotated to the "Operate" position, the input circuit breaker may be closed, placing the frequency converter in operation.

After the frequency converter has achieved stable operation and is in synchronism with the load line the output power circuit breaker may be closed. With the control switch in the "Operate" position the shunt-trip circuits of the input power and output power circuit breakers are thereafter under control of the "Fault-trip" logic.

### 2.2.2 System Operation. When the control logic switch described above is placed in the "Operate" position the logic for the inverter is operational, but gate drive for the power SCR's is clamped off on the primary side of the SCR drive transformers. The high voltage DC filter capacitors are precharged to approximately 400VDC. This precharging serves to eliminate a surge of inrush current when the input power circuit breaker is closed.

**2.2.3 Input Rectification.** Closure of the input AC power circuit breaker connects the three-phase AC power from the mains to the primary of the full isolation input power transformer having a wye and a delta secondary. The input power transformer secondary windings connect to two three-phase silicon bridge rectifiers. These two bridge rectifiers are provided with AC voltage from the delta and wye transformer secondary windings which are displaced 30 degrees from each other. The result is that the ripple voltage has a 720 Hz ripple frequency (12 times base frequency) in the rectified DC.

Harmonic current generated by the action of the rectifiers is the 11th harmonic of the fundamental, or 660 Hz. This is easily suppressed as compared with the problem of filtering 5th harmonic voltages which would be produced if a single three-phase bridge rectifier were used.

Computer grade electrolytic capacitors are used to reduce the high voltage DC ripple voltage to less than 0.25 percent. This results in modulation voltage of less than 0.25 percent in the 400 Hz AC output voltage.

**2.2.4 Power Inversion.** High voltage DC power (400VDC) connects to three single-phase SCR inverters. Each SCR inverter uses four power SCR's arranged in a single-phase bridge circuit. The use of three individual SCR bridge circuits permits each of the three phases of AC output power to be individually voltage regulated. Thus output voltage regulation may be maintained accurately even under conditions of extreme load unbalance.

Each SCR bridge is arranged in two "half-bridge" circuits. Each "half-bridge" generates a square wave of AC voltage. By phase shifting action on these two square waves of voltage, a "quasi-square wave" of voltage is generated, having a controllable fundamental 400 Hz output voltage. The harmonic voltages present in the quasi-square wave are filtered by the "harmonic filter" on the 400 Hz output.

The SCR bridge is used not only as an inverter to connect DC power to 400 Hz power, but also as an "ON-OFF" switch. When one of the "Fault Monitors" senses an error in operation, the SCR bridge is switched to "OFF". When input power is turned on by action of the input AC power circuit breaker the SCR bridge is commanded to turn "ON". This eliminates the need for a high voltage DC contactor. DC contactors are generally "high failure rate" components because of their tendency to have contacts welded closed when DC power arcs occur as a result of contact bounce.

The four power SCR's in the SCR bridge are commutated off by means of four commutation SCR's which carry only commutation current. The commutation capacitors, reactors, transformers, and diodes complete the commutation circuit.

Each of the three SCR bridge inverters are individually protected by a current limiting fuse.

Output power from the three SCR bridge circuits connect through harmonic filter reactors to the primary of a three-phase output power transformer. The function of the three harmonic filter reactors is to limit the flow of harmonic current to the output, while providing only minimal impedance to the fundamental component of AC output power.

**2.2.5 Output Power Circuits.** Output filtering of the harmonic voltage takes advantage of the symmetry of the SCR generated quasi-square wave of 400 Hz voltage to eliminate all even harmonic voltages. The phase relationships between the three quasi-square waves of voltage permit elimination of all odd harmonics which are multiples of three. Thus eliminating the 3rd, 9th, 15th harmonic voltage, etc. The principal remaining harmonic voltages are the 5th, 7th, 11th and 13th.

A series inductor-capacitor shunt filter specifically tuned to the 5th harmonic, reduces this harmonic to less than 2 percent. Shunt filter capacitors are all that are required to bring all the higher harmonic voltages to within 1 percent. Total harmonics are less than 3 percent RMS.

**2.2.6 Control Logic.** The control and logic assembly contains the voltage regulation, frequency sensing and time circuits; SCR logic drive circuitry; and parallel sync circuits required for system operation. Protective circuits are incorporated within the assembly to isolate or prevent overloads to critical components and subassemblies. The control and logic assembly interfaces with all other frequency converter assemblies in performance of system functions.

The control and logic assembly contains three identical phase regulator subassemblies. These regulators contain the circuitry, amplifiers and gates for output sensing and for wave formations. The frequency control utilizes a crystal which is so accurate that a frequency meter on a control panel is superfluous, since the crystal is far more accurate than any panel meter.

**2.2.7 Converter Output Characteristics.** Figure 2-3 shows three oscilloscope photos of the output of the frequency converter, rated 75 KVA.

The two upper photos show the output voltage line-to-line waveform for no-load and full load conditions. The measured total harmonics were 1.8 percent and 1.4 percent, respectively. The bottom photo shows the voltage transients for a zero to full load change with the current trace at the bottom. The voltage transient is less than 10 percent and recovers in approximately 5 ms. As can be seen, the results confirm the design characteristics of table 2-2 regarding harmonic distortion and voltage transients.

Communication between converters is by a connecting signal level cable. If the unit containing the master oscillator should fail or be taken off line, another unit will automatically become the master. When a new unit is brought on line, synchronization occurs automatically.

TABLE 2-1

EQUIPMENT AND SERVICES AVAILABLE

<u>Item</u>	<u>QTY</u>	<u>Description</u>
1	2 to 6	Solid-State Frequency Converter modules, parallelable, rated 250 KW/313 KVA, 4160VAC, 3-ph, 3-w, 60 Hz input, and 4160VAC, 3-ph, 3 or 4-w, 400 Hz output.
2	1	System switchgear and control assembly containing module input and output circuit breakers, controls, metering and alarms.
3	1	Remote monitor panel as described in Paragraph 2.6 of this proposal.
4	Lot	Prefabricated interconnection power cables; plug-in control cables between modules and system switchgear and control assembly.
5	Lot	Complete installation of above defined equipment.

**TABLE 2-2**  
**SYSTEM CHARACTERISTICS**

**Input Power**

Input voltage and frequency nominal	4160 VAC, 3-phase, 4-wire, 60 Hz.
Input voltage range	$\pm 10\%$ from nominal.
Input frequency range	$\pm 3$ Hz from nominal.
Input current, 480 VAC input	48 amps per line, maximum per module.
Input pf @ 25% load	.81.
Input pf @ 50% load	.82.
Input pf @ 75% load	.84.
Input pf @ 100% load	.85.

Efficiency (6 modules: full load = 1565 KVA at 0.8 pf)

Efficiency @ 25% load	82%.
Efficiency @ 50% load	86%.
Efficiency @ 75% load	89%.
Efficiency @ 100% load	90%.
Harmonic current feedback	10%, maximum.
Inrush current	Full load current maximum.
Voltage transient acceptance	30%.
overvoltage, 1/2 cycle	
Voltage transient acceptance	25 KV volt peak.
50 microseconds	

**Output Power**

Voltage, nominal	4160 VAC, 3-phase, 3-wire.
KVA rating, nominal	1565 KVA, redundant, at full capacity.
Load current, nominal	217 amps per line.
Load power factor, nominal	0.8 lagging.
Power rating	1250 KW.
Frequency, nominal	400 Hz.

TABLE 2-2

Page Two

Voltage adjustment range	$\pm 5\%$ .
Power factor load range	0.5 lagging to 0.7 leading.
Voltage regulation	$\pm 0.5\%$ .
Frequency tolerance	$\pm 0.1\%$ .
Harmonic voltage, single with linear load	2 RMS, maximum.
Harmonic voltage, total with linear load	3RMS, maximum.
Deviation factor, any linear load	5% maximum.
Voltage balance for balanced load	$\pm 0.25\%$ .
Voltage balance for 15% unbalanced load	$\pm 0.5\%$ .
Voltage modulation, any load	0.25% maximum.
Voltage transients:	
20% load step applied	2% maximum.
20% load step dropped	2% maximum.
100% load step applied	10% maximum.
100% load step dropped	10% maximum.
10% transient on AC input line	5% maximum.
Switching of one module off line	2% maximum with 3 modules or more.
Voltage transient recovery time	5 ms, maximum.
Overload, 110%	1 hour.
Overload, 125%	15 min.
Overload, 150%	2 minutes.
Short Circuit available current	300% for first cycle declining to 200% unit fault clears.
Current load sharing with parallel identical units	within 5%.

## RELIABILITY, MAINTAINABILITY & ENVIRONMENTAL CHARACTERISTICS

Mean-Time-Between-Failure per MIL Handbook 217A (nonredundant)	5,000 hours, minimum.
Mean-Time-Between-Failure per historical data on similar converters	15,000 hours, minimum.
Mean-Time-Between-Failure (system level)	100,000 hours, minimum.
Mean-Time-Between-Repair, calculated	20 minutes.
Maximum Time to Repair	210 minutes.
Temperature range	0 to 40 degrees C. 32 degrees F to 104 degrees F.
Acoustic noise on "A" scale at distance of 5 feet	75 db maximum per ASA S1.4.
Conducted electromagnetic noise	20 db maximum above MIL-STD-461A Class IIIB radiated.

CONDUCTOR RESISTANCE EFFECTS AT HIGH FREQUENCIES

D. J. Mulvey  
General Electric Company  
Bridgeport, Connecticut

INTRODUCTION

The increasing use of power systems at frequencies above 60 cycles has brought about increased interest in the rating of cables for such frequencies.

The several factors influencing effective conductor resistance are of considerable magnitude as frequency increases, and for efficient cable application they must be considered.

This report will identify some of these effects and give a suggested method for determining the capacity of cables at 400 and 800 cycles as related to their capacity at 60 cycles.

In general, three-phase 400 or 800-cycle power systems are designed in the same way that 60-cycle systems are designed, with the realization that the increased frequency will increase the skin and proximity effects in the conductors thereby increasing the effective conductor resistance. The increased frequency also increases the circuit reactance which combined with the resistance increases the voltage drop.

The higher frequencies will also increase the effect of magnetic materials upon cable reactance and heating. For this reason the cables should not be run in magnetic conduit or too close to magnetic structures in the building. The losses due to frequency are proportional to the square of the line current, and so for very small currents they may be negligible. For instance, in the 400 cycle lighting circuit in the Union College Field House, #12 AWG conductors in standard steel conduit were used. In this case, there is a fluorescent lighting load of thirty-five eight-foot lamps. Each #12 AWG circuit carries only 6.6 amperes. After the installation was completed, voltage readings at various fixtures showed that the voltage drops were not excessive, and that no real gain would have resulted from use of fibre or non-magnetic conduit. (1) Pending further tests, the use of magnetic conduit should be avoided for circuits employing conductor sizes larger than about #6 AWG for 400 cycles and #10 AWG at 800 cycles.

In the discussion that follows we will consider only cables in air or in non-metallic conduit. Also, the cables will be single conductor 600 volt rated non-metallic-covered types of the rubber-neoprene variety in common use. Such data will be usable with reasonable accuracy for other types of single conductor cables such as thermoplastic, rubber-braided or varnished cambric cables.

For frequencies up to about 1000, the reactance can be taken as directly proportional to the frequency. This neglects the reduction in inductance due to frequency, but this change is not large and the error is negligible. For higher frequencies the inductance correction should be included. In such cases the inductance is given by the following:

$$L = \left( 0.1404 \log_{10} \frac{2S}{D_c} + .0153 \frac{L}{L_0} \right) \times 10^{-3} \text{ Henries per M ft.}$$

$L$  = Inductance to neutral.

$L/L_0$  = Correction from Table I.

$S$  = Axial spacing between conductors - inches.

$D_c$  = Conductor diameter - inches.

# CALCULATION OF RESISTANCE RATIOS

Neher and McGrath (2) show that for any cable system the AC/DC resistance ratio of the conductor may be expressed

$$R_{ac}/R_{dc} = 1 + Y_c + Y_s + Y_p \quad (1)$$

where  $Y_c$ ,  $Y_s$ , and  $Y_p$  are the effects due to the conductor, sheath and conduit respectively. Since we are concerned with non-metallic sheaths in air or non-metallic conduit, only  $Y_c$  will be considered here. Neher and McGrath also show that  $Y_c$  can be expressed as  $Y_{cs} + Y_{cp}$ , where  $Y_{cs}$  is the conductor component due to skin effect and  $Y_{cp}$  due to proximity effect. Then

$$R_{ac}/R_{dc} = 1 + Y_{cs} + Y_{cp} \quad (2)$$

The skin effect and proximity effect are determined from the function  $F(x)$  which for solid and concentric round conductors is given in Table I. Then we have

$$Y_{cs} = F(x) \quad (3)$$

$$Y_{cp} = F(x) K^2 \left[ \frac{1.18}{F(x) + .27} + .312 K^2 \right] \quad (4)$$

where  $K = \frac{D_c}{S}$

$$x = .0276 \sqrt{\frac{f}{R_{dc}}}$$

$f$  = Frequency in cycles per second.

$R_{dc}$  = Conductor direct current resistance at operating temperature, ohms per 1000 feet.

$D_c$  = Conductor diameter - inches.

$S$  = Axial spacing between conductors - inches.

$F(x)$  = Function of  $x$  from Table I.

Equations (3) and (4) are from the Neher-McGrath paper.

Data from Table II are given in graphical form in Figure 1. It is interesting to note that the skin and proximity effect ratios given in Table II are within a very few percent of the values given for values of  $\sqrt{\frac{f}{R_{dc}}}$  up to 150 in Reference (4).

Presumably the values in that reference were calculated for telephone conductors by methods different from those used here for power conductors.

Table III gives the AC/DC resistance ratios at 400 and 800 cycles per second for typical 600 volt single conductor rubber-neoprene cables in close triangular configuration in air or non-metallic conduit. Table III also gives the current derating factors based on the formula

$$\text{Derating Factor} = \sqrt{\frac{1}{AC/DC}}$$

The ampacity of a given cable size at 400 or 800 cps can be determined by multiplying the 60 cycle rating by the corresponding derating factor. For the larger sizes, the deratings are on the conservative side in that they actually are based on DC ratings of the conductors. The small error, on the safe side, can be considered negligible in view of possible variations in insulation thicknesses, etc.

It will be noted that the resistance ratios given here are based on Equation (1) and do not include losses in any metal sheath, armor, or conduit. Losses in a thin aluminum armor tape may be small but those in a metal conduit could be large enough to cause trouble if currents are large.

To evaluate such losses and their effect on the cable ratings requires the calculation  $Y_s$  and  $Y_p$  in Equation (1). Empirical formulas for 60 cycles are available but, as far as is known to the author, there is no simple method of calculation of these sheath or pipe losses for higher frequencies. Such a method would be very useful.

#### REFERENCES

1. Cooper, Berlon C. - "High Cycle Lighting Comes of Age" ELECTRICAL CONSTRUCTION AND MAINTENANCE, JUNE 1955.
2. Neher, J. H. and McGrath, M. E. - AIEE Transactions Paper 57-650, "The Calculation of the Temperature Rise and Load Capability of Cable Systems".
3. Rees, H. H. and Larrick, C. V. - AIEE Paper 42-81, "High Frequency Coaxial Line Calculations".
4. Herbert, C.M. - "Transmission Characteristics of Toll Telephone Cables at Carrier Frequencies" - Bell System Technical Journal, July 1941

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TABLE I

SKIN-EFFECT RESISTANCE AND INDUCTANCE EFFECTS  
FOR SOLID ROUND AND CONVENTIONAL STRANDED CONDUCTORS

x	F(x)	L/L <sub>0</sub>	x	F(x)	L/L <sub>0</sub>
0.0	0.00000	1.00000	2.5	0.17538	0.91347
0.1	0.00000	1.00000	2.6	0.20056	0.90126
0.2	0.00001	1.00000	2.7	0.22753	0.88825
0.3	0.00004	0.99999	2.8	0.25820	0.87451
0.4	0.00013	0.99993	2.9	0.28644	0.86012
0.5	0.00032	0.99984	3.0	0.31809	0.84517
0.6	0.00067	0.99966	3.5	0.49202	0.76550
0.7	0.00124	0.99937	4.0	0.67787	0.66632
0.8	0.00212	0.99894	4.5	0.86275	0.61563
0.9	0.00340	0.99830	5.0	1.04372	0.55597
1.0	0.00519	0.99741	6.0	1.39359	0.46521
1.1	0.00758	0.99621	7.0	1.74319	0.40021
1.2	0.01071	0.99465	8.0	2.09445	0.35107
1.3	0.01470	0.99266	9.0	2.44638	0.31257
1.4	0.01958	0.99017	10.0	2.79857	0.28162
1.5	0.02582	0.98711	11.0	3.15100	0.25622
1.6	0.03323	0.98342	12.0	3.50358	0.23501
1.7	0.04203	0.97904	13.0	3.85831	0.21703
1.8	0.05240	0.97390	14.0	4.20915	0.20160
1.9	0.06440	0.96795	15.0	4.56205	0.18822
2.0	0.07818	0.96113	20.0	6.32767	0.14128
2.1	0.09375	0.95343	25.0	8.09412	0.11307
2.2	0.11126	0.94482	30.0	9.88101	0.09424
2.3	0.13069	0.93527	40.0	13.39545	0.07069
2.4	0.15207	0.92482	50.0	16.93032	0.05656
			60.0	20.46541	0.04713
			80.0	27.53593	0.03535
			100.0	34.60566	0.02828
					0.00000

$$x = .0276 \sqrt{\frac{f}{R_{dc}}} \leftarrow = \text{dc resist. of wire per 1000 FT}$$

This table adapted from Reference (3), Table I.

TABLE II

AC/DC RESISTANCE RATIOS AS CALCULATED FROM EQUATIONS (3) AND (4)  
- SKIN AND PROXIMITY EFFECTS -

AC/DC RATIO						
B	K = 0	K = .4	K = .5	K = .6	K = .7	K = .8
0	1.000	1.000	1.000	1.000	1.000	1.000
10	1.000	1.000	1.000	1.000	1.000	1.001
20	1.000	1.001	1.001	1.001	1.002	1.003
30	1.003	1.004	1.005	1.006	1.008	1.010
40	1.008	1.013	1.017	1.020	1.025	1.031
50	1.019	1.031	1.038	1.047	1.057	1.070
60	1.038	1.062	1.076	1.093	1.113	1.141
70	1.069	1.108	1.130	1.158	1.192	1.232
80	1.115	1.172	1.206	1.247	1.297	1.355
100	1.245	1.337	1.391	1.457	1.539	1.637
150	1.731	1.875	1.959	2.071	2.210	2.375
200	2.226	2.391	2.492	2.625	2.791	3.001
250	2.708	2.885	2.996	3.144	3.333	3.580
500	5.139	5.350	5.495	5.702	5.984	6.379
800	8.059	8.297	8.482	8.752	9.139	9.689
1000	10.023	10.279	10.487	10.801	11.253	11.913

$$B = \sqrt{\frac{f}{R_{dc}}}$$

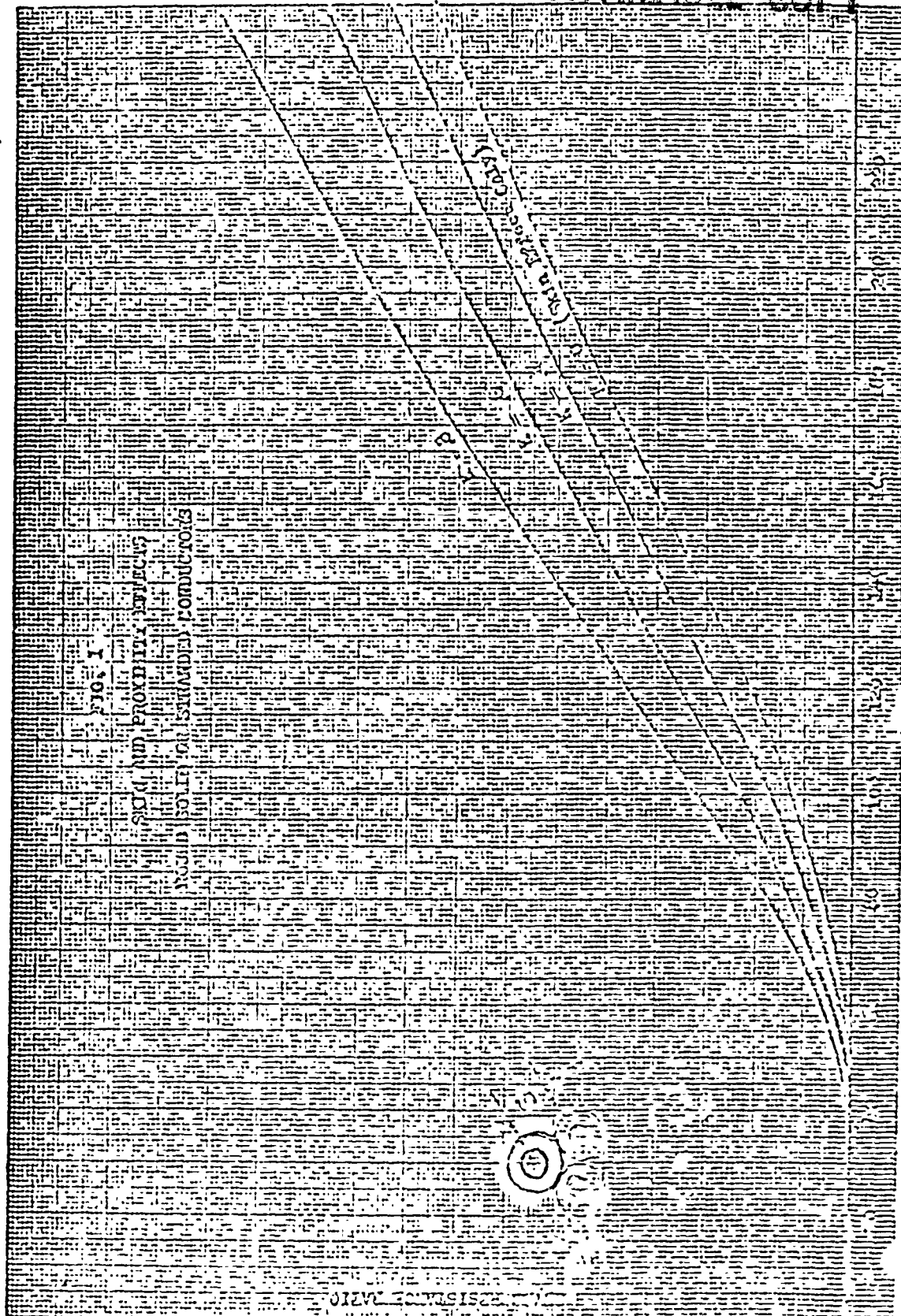
$K = \frac{D_c}{S}$  ; when  $K = 0$ , ratio is for skin effect only.

TABLE III

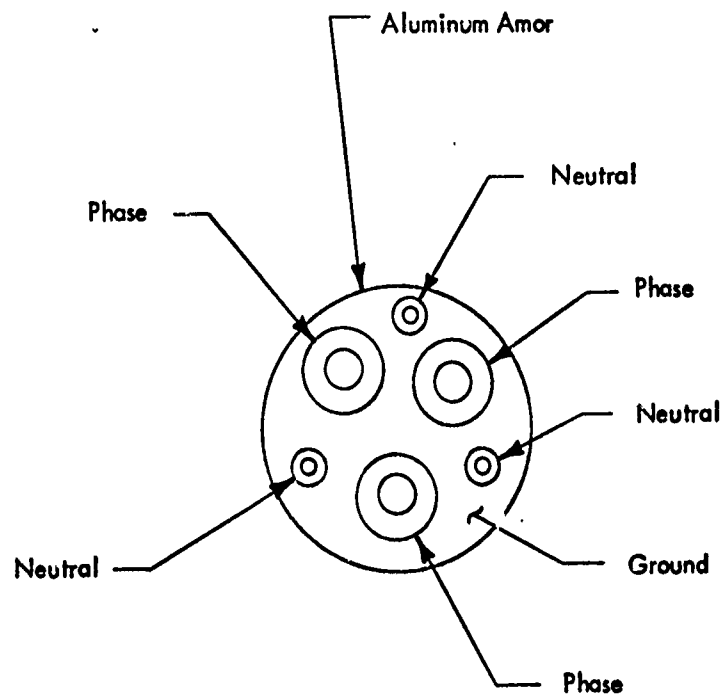
600 VOLT RUBBER-NEOPRENE CABLES  
STRANDED COPPER - MINIMUM TRIANGULAR SPACING  
IN AIR OR NON-METALLIC CONDUIT

Cable Size AWG or MM	Cond. Dia. Inches	Cable Dia. Inches	K	DC Res. 75°C	60 Cycles per Sec.			800 Cycles per Sec.		
					B	AC/DC	Current Derating Factor	B	AC/DC	Current Derating Factor
14	.073	.21	.35	3.14	11.3	1.00	1.00	16	1.00	1.00
12	.092	.23	.40	1.97	14.3	1.00	1.00	20.2	1.00	1.00
10	.117	.25	.47	1.24	18	1.00	1.00	25.4	1.00	1.00
8	.148	.32	.46	.780	22.7	1.00	1.00	32	1.00	1.00
6	.186	.39	.48	.490	28.6	1.00	1.00	40.5	1.00	1.00
4	.234	.44	.53	.310	36	1.00	1.00	51	1.05	.93
2	.296	.50	.59	.194	45.4	1.00	1.00	64.4	1.12	.94
1	.333	.61	.55	.154	51	1.05	.98	72.2	1.16	.93
0	.374	.65	.58	.122	57.4	1.08	.96	81	1.25	.89
00	.420	.69	.61	.097	64.5	1.15	.93	91	1.40	.84
000	.471	.75	.63	.0757	72.3	1.22	.90	102	1.53	.81
0000	.529	.81	.65	.0608	81.4	1.33	.87	115	1.70	.77
250	.576	.92	.63	.0515	89.1	1.40	.84	125	1.82	.74
350	.661	1.08	.63	.0368	105	1.55	.80	148	2.05	.70
500	.814	1.16	.70	.0258	125	1.90	.72	177	2.54	.63
750	1.000	1.38	.73	.0172	153	2.30	.66	216	3.06	.57
1000	1.150	1.54	.75	.0129	177	2.60	.62	249	3.44	.54

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APPENDIX 'K'



LV LINE CABLE CONSTRUCTION  
600 VOLT





# **500-V KATHENE® INSULATED CONDUCTOR SPECIFICATION 600 AND RELATED AERIAL AND ARMORED CABLE ASSEMBLIES** NOTES: Conduit sizes based on 43% fill for 3-1/c cables. Electrical properties based on All ampacities have been individually calculated for one isolated circuit in 40C still air or in earth ambient at 90C. AC resistance includes skin and proximity effects. (To correct reactance for effects on impedance and voltage drop due to random lay, see page 14.) IPCEA . . . Cable Ampacities Publication S-135-1/P-46-426, Vol. 1.

PRODUCT	SPECIFICATIONS	CONDUCTOR SIZE—AWG OR MCM															
		6	4	2	1	1/0	2/0	3/0	4/0	250	300	350	400	500	600	700	1000
SINGLE CONDUCTOR DETAIL	O.D. inches	.31	.36	.42	.49	.54	.58	.63	.69	.77	.83	.88	.93	1.01	1.12	1.19	1.23
	Number of strands	7	7	7	19	19	19	19	19	37	37	37	37	37	61	61	61
	Insulation thickness, inches	.062	.062	.062	.078	.078	.078	.078	.078	.094	.094	.094	.094	.094	.109	.109	.109
	Weight, lbs./M'	52	71	105	135	160	195	240	290	350	405	460	520	625	755	865	1190
3-1/C OR TRIPLEXED CABLE DETAIL	Conduit size, inches, 43% fill	1	1 1/4	1 1/2	2	2	2	2	2 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	4
	In non-mag conduit	.847	.532	.335	.265	.210	.167	.133	.106	.0894	.0747	.0641	.0564	.0456	.0382	.0331	.0241
	Ind. react., ohms/M'	.035	.033	.032	.031	.031	.030	.029	.028	.0287	.0283	.0279	.0276	.0269	.0267	.0267	.0260
	Impedance, ohms/M'	.848	.533	.337	.267	.212	.170	.136	.110	.0939	.0799	.0699	.0628	.0529	.0468	.0425	.0355
AERIAL CABLE ASSEMBLY SPECIFICATION 402	In mag conduit	.847	.532	.335	.265	.210	.167	.133	.106	.0897	.0750	.0645	.0569	.0460	.0390	.0339	.0320
	Ind. react., ohms/M'	.048	.041	.040	.039	.039	.038	.036	.035	.0359	.0354	.0349	.0345	.0336	.0339	.0334	.0325
	Impedance, ohms/M'	.848	.534	.338	.268	.214	.171	.138	.112	.0966	.0829	.0733	.0665	.0570	.0517	.0476	.0412
	In cond., in air	58	76	102	116	137	157	183	210	237	268	300	324	380	422	464	481
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 WITH 1 GROUND WIRE	In duct, 75% LF	70	91	120	138	158	182	208	240	266	297	325	352	402	449	490	509
	In duct, 100% LF	66	86	114	131	150	172	196	226	250	277	305	328	374	417	454	472
	Direct burial, 75% LF	105	135	175	201	229	260	296	338	370	410	448	482	543	600	652	677
	Direct burial, 100% LF	96	123	160	182	206	231	266	303	331	368	398	428	481	532	576	596
ALUMINUM ARMORED 4/C CABLE SPECIFICATION 408 WITH 2 GROUND WIRES	In non mag. conduit	.0852	.0702	.0595	.0536	.0503	.0462	.0431	.0400	.0385	.0371	.0363	.0352	.0348	.0342	.0342	.0341
	In non-mag duct	.0969	.0794	.0665	.0606	.0551	.0506	.0462	.0431	.0407	.0383	.0369	.0366	.0343	.0338	.0334	.0338
	In magnetic conduit	.0852	.0703	.0597	.0538	.0508	.0465	.0437	.0407	.0397	.0385	.0381	.0373	.0375	.0378	.0383	.0408
	In direct burial	.1410	.1136	.0934	.0842	.0756	.0692	.0627	.0577	.0538	.0507	.0482	.0466	.0441	.0431	.0424	.0422
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 WITH 1 GROUND WIRE	Mem. size, inches	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5	6	6 1/2	7	8
	Breaking strength, lbs.	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720
	DC res., ohms/M', 20C	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526	.4526
	Assemb. wt., lbs./M'	305	365	465	565	640	750	885	1040	1225	1390	1560	1740	2060	2535	2870	3040
ALUMINUM ARMORED 4/C CABLE SPECIFICATION 408 WITH 2 GROUND WIRES	AC res., ohms/M'	.847	.532	.335	.265	.210	.167	.133	.106	.0894	.0747	.0641	.0567	.0456	.0382	.0331	.0310
	Ind. react., ohms/M'	.035	.033	.032	.031	.031	.030	.029	.028	.0287	.0283	.0279	.0276	.0269	.0267	.0267	.0260
	Impedance, ohms/M'	.848	.533	.337	.267	.212	.170	.136	.110	.0939	.0799	.0699	.0628	.0529	.0468	.0425	.0355
	Ampacity, amps.	69	91	123	144	167	193	224	262	292	328	364	398	460	523	576	604
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 WITH 1 GROUND WIRE	V drop/circ. ft., -	.1013	.0840	.0718	.0666	.0613	.0568	.0528	.0499	.0475	.0454	.0441	.0433	.0421	.0424	.0424	.0445
	Diam. over armor, approx. inches	.95	1.05	1.18	1.33	1.41	1.52	1.62	1.77	1.94	2.06	2.17	2.27	2.45	2.69	2.84	2.92
	Diam. under armor, approx. inches	.70	.80	.93	1.08	1.16	1.27	1.37	1.51	1.68	1.80	1.91	2.01	2.19	2.43	2.58	2.66
	Armor thickness, inches	.025	.025	.025	.025	.025	.025	.025	.030	.030	.030	.030	.030	.030	.030	.030	.030
ALUMINUM ARMORED 4/C CABLE SPECIFICATION 408 WITH 2 GROUND WIRES	Ground wire size, AWG or MCM	14	10	10	8	8	6	6	4	4	3	2	2	1	1/0	2/0	3/0
	Assembled wt., approx. lbs/M'	245	340	450	570	705	805	1030	1160	1465	1690	1870	2110	2530	3025	3465	3640
	AC resistance, ohms/M'	.847	.532	.335	.265	.210	.167	.133	.106	.0894	.0747	.0641	.0564	.0456	.0382	.0331	.0310
	Inductive reactance, ohms/M'	.035	.033	.032	.031	.031	.030	.029	.028	.0287	.0283	.0279	.0276	.0269	.0267	.0267	.0260
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 WITH 1 GROUND WIRE	Impedance, ohms/M'	.848	.533	.337	.267	.212	.170	.136	.110	.0939	.0799	.0699	.0628	.0529	.0468	.0425	.0355
	Ampacity, amps	65	85	115	135	155	180	205	240	265	300	330	355	410	460	505	530
	V drop/circ. ft., -	.0955	.0785	.0671	.0624	.0569	.0530	.0483	.0457	.0431	.0415	.0400	.0386	.0376	.0373	.0372	.0384
	Diam. over armor, approx. inches	—	—	1.28	1.45	1.54	1.65	1.78	1.92	2.13	2.26	2.38	2.50	2.70	2.97	3.14	3.22
ALUMINUM ARMORED 4/C CABLE SPECIFICATION 408 WITH 2 GROUND WIRES	Diam. under armor, approx. inches	—	—	1.04	1.19	1.29	1.40	1.52	1.66	1.87	2.00	2.12	2.23	2.44	2.71	2.88	2.96
	Armor thickness, inches	—	—	.025	.025	.025	.025	.030	.030	.030	.030	.030	.030	.030	.030	.030	.030
	Ground wire size, AWG or MCM	—	—	8	6	6	4	4	2	2	1	1	1/0	2/0	3/0	4/0	5/0
	Assembled wt., approx. lbs/M'	—	—	605	770	890	1065	1290	1550	1855	2145	2400	2690	3225	3860	4420	4550
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 WITH 1 GROUND WIRE	AC resistance, ohms/M'	—	—	.335	.265	.210	.167	.132	.105	.0853	.0745	.0640	.0562	.0452	.0380	.0329	.0308
	Inductive reactance, ohms/M'	—	—	.039	.039	.038	.037	.036	.035	.0345	.0336	.0329	.0321	.0309	.0301	.0289	.0287
	Impedance, ohms/M'	—	—	.337	.268	.213	.171	.137	.111	.0957	.0817	.0720	.0647	.0548	.0485	.0438	.0421
	Ampacity, amps	—	—	105	120	140	160	185	215	240	275	305	325	375	420	465	485
ALUMINUM ARMORED 4/C CABLE SPECIFICATION 408 WITH 2 GROUND WIRES	V drop/circ. ft., -	—	—	.0671	.0624	.0569	.0530	.0483	.0457	.0431	.0415	.0400	.0386	.0376	.0373	.0372	.0375
	Diam. over armor, approx. inches	—	—	1.28	1.45	1.54	1.65	1.78	1.92	2.13	2.26	2.38	2.50	2.70	2.97	3.14	3.22
	Diam. under armor, approx. inches	—	—	1.04	1.19	1.29	1.40	1.52	1.66	1.87	2.00	2.12	2.23	2.44	2.71	2.88	2.96
	Armor thickness, inches	—	—	.025	.025	.025	.025	.030	.030	.030	.030	.030	.030	.030	.030	.030	.030

voltage drops shown are for full ampacity 100%, L.F.

# 5-KV UNSHIELDED KATHENE<sup>®</sup> INSULATED ALUMINUM CONDUCTOR SPECIFICATION 463 AND RELATED AERIAL AND ARMORED CABLE ASSEMBLIES

NOTES Conduit sizes based on 43% fill for 3-1/c cables. Electrical properties based on All ampacities have been individually calculated for one isolated circuit in 40C still air  
triplexed cable—conductor at 90C. AC resistance includes skin and proximity effects. (To or in 20C earth, ambient at RHO-90 in accordance with the procedures as specified in AIEE/  
correct reactance for effects on impedance and voltage drop due to random lay, see page 14). IPCEA Power. — Ampacities Publication S-135-1/P-46-426, Vol. 1.

PRODUCT	SPECIFICATIONS	CONDUCTOR SIZE — AWG OR MCM																	
		6	4	2	1	1/0	2/0	3/0	4/0	2 1/2	3	350	400	500	600	700	750	1000	
SINGLE CONDUCTOR DETAIL 	O.D. inches	.42	.47	.53	.57	.61	.66	.71	.77	.84	.89	.94	.99	1.07	1.19	1.26	1.29	1.46	
	Number of strands	7	7	7	19	19	19	19	19	37	37	37	37	37	61	61	61	61	
	Insulation thickness, inches	.110	.110	.110	.110	.110	.110	.110	.110	.120	.120	.120	.120	.120	.130	.130	.130	.130	
	Weight, lbs./M'	71	93	125	145	175	205	245	295	350	405	460	520	6.5	750	860	910	1180	
	Conduit size, inches, 43% fill	1 1/4	1 1/4	1 1/4	1 1/2	2	2	2	2	2 1/2	2 1/2	3	3	3	3 1/2	3 1/2	3 1/2	4	
3-1/C OR TRIPLEXED CABLE DETAIL 	In non-mag conduit	.847	.532	.335	.265	.210	.167	.133	.105	.0894	.0746	.0640	.0563	.0453	.0381	.0330	.0309	.0239	
	Ind. react., ohms/M'	.042	.040	.037	.035	.034	.033	.032	.031	.0307	.0300	.0295	.0291	.0284	.0287	.0280	.0273	.0273	
	Impedance, ohms/M'	.848	.534	.337	.267	.213	.170	.137	.109	.0945	.0804	.0705	.0634	.0535	.0477	.0433	.0412	.0363	
	AC res., ohms/M'	.847	.532	.335	.265	.210	.167	.133	.106	.0896	.0750	.0644	.0568	.0459	.0388	.0338	.0318	.0252	
	Ind react., ohms/M'	.053	.050	.046	.048	.043	.041	.040	.039	.0384	.0375	.0369	.0364	.0355	.0359	.0350	.0341	.0341	
AERIAL CABLE ASSEMBLY SPECIFICATION 402 	Impedance, ohms/M'	.849	.534	.338	.269	.214	.172	.139	.113	.0975	.0839	.0742	.0675	.0580	.0529	.0487	.0466	.0424	
	In cond., in air	58	76	102	116	137	157	183	210	237	268	300	324	380	422	464	481	572	
	Ampacity in duct, 75% LF	70	91	120	138	158	182	208	240	266	297	325	352	402	449	490	509	597	
	In duct, 100% LF	66	86	114	131	150	172	196	226	250	277	305	328	374	417	454	472	550	
	Direct burial, 75% LF	105	135	175	201	229	260	296	338	370	410	448	482	543	600	652	677	788	
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 (with 3 ground wires if required) 	Direct burial, 100% LF	96	123	160	182	206	235	266	303	331	366	398	428	481	532	576	596	689	
	Nom size, inches	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	Breaking strength, lbs.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	DC res., ohms/M', 20C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	Assemb diam., inches	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 (with 3 ground wires if required) 	Assemb wt lbs/M'	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	AC res., ohms/M'	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	Ind react., ohms/M'	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	Impedance, ohms/M'	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	Ampacity, amps.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 (with 3 ground wires if required) 	Diam over armor, approx. inches	1.19	1.30	1.42	1.51	1.60	1.70	1.82	1.94	2.09	2.21	2.32	2.42	2.60	2.83	3.00	3.07	3.44	
	Diam under armor, approx inches	.94	1.05	1.17	1.26	1.35	1.45	1.56	1.68	1.83	1.95	2.06	2.16	2.34	2.57	2.74	2.81	3.18	
	Armor thickness, inches	.025	.025	.025	.025	.025	.025	.025	.030	.030	.030	.030	.030	.030	.030	.030	.030	.030	
	Ground wire size, AWG or MCM	14	10	10	8	8	6	4	4	4	3	2	2	1	1/0	2/0	2/0	3/0	
	Assembled wt., approx. lbs/M'	375	480	595	690	795	935	1160	1330	1530	1750	1980	2185	2590	3080	3530	3700	4700	
ALUMINUM ARMORED 3/C CABLE SPECIFICATION 408 (with 3 ground wires if required) 	AC resistance, ohms/M'	.847	.532	.335	.265	.210	.167	.133	.105	.0894	.0746	.0640	.0563	.0453	.0381	.0330	.0309	.0239	
	Inductive reactance, ohms/M'	.042	.040	.037	.035	.034	.033	.032	.031	.0307	.0300	.0295	.0291	.0284	.0287	.0280	.0273	.0273	
	Impedance, ohms/M'	.848	.534	.337	.267	.213	.170	.137	.109	.0945	.0804	.0705	.0634	.0535	.0477	.0433	.0412	.0363	
	Ampacity, amps.	65	85	115	135	155	180	205	240	265	300	330	355	410	460	505	530	625	

APPENDIX 'L'

J A R O S', B' A U M · & B O L L E S Consulting Engineers

August 11, 1976

General Electric Company  
PO Box 2830  
Los Angeles, California 90051

Attention: Mr. J. Roberts

Re: Feasibility Study - Centralized 60/400 HZ  
Generation & Distribution System

Gentlemen:

This office is under contract with the United States Naval Facility Engineering Command to prepare a feasibility study for a centralized 60/400 HZ generation and distribution system at 4.16 KV.

The application intended is in the generation and distribution of 400 HZ power at Naval Air Stations throughout the United States.

Your company has been selected as a potential supplier of the electrical equipment checked below which will be required for the 400 HZ power systems. A full disclosure of information requested will aid the U.S. Navy in decisions relating to the method of supplying 400 HZ power at many locations, and may represent a significant sales opportunity to your company.

Equipment requirements will include:

- ✓ 1. Motor generator sets, 60 HZ/400 in power ranges from 100 KVA to 500 KVA and with output at 3 phase, 4160 VAC.
- ✓ 2. Switchgear suitable for 400 HZ power distribution.
- ✓ 3. 5 KV insulated wire, 3 phase, 4160 VAC, 400 HZ distribution, suitable for direct burial underground or overhead, run in conduit, duct bank or interlocked armor.
- ✓ 4. Step down power transformers, in combination with voltage regulators or line drop compensators to maintain acceptable steady state voltage limits in power ranges from 30 to 400 KVA.
- 5. Electromagnetic filters to minimize the transmission of EMI noise from one load to another via the HV power transmission lines.

J A R O S ,   B A U M   &   B O L L E S   Consulting Engineers

A set of questionnaires covering the motor-generators, 5 KV cable, transformers and voltage regulators is included herewith. Please return the questionnaires with appropriate answers and submit a technical proposal backed up with supporting literature, or as a minimum, catalog cuts of the equipment in which you may have an interest. Also, please provide budgetary cost for the equipment based on procurement in 1977.

We require your submission not later than September 17, 1976.

Very truly yours,

---

Paul Katzaroff  
JAROS, BAUM & BOLLES

PK:jim

Enclosure

(1)	(2)	(3)	(4)	(5)
<u>Switchgear</u> <u>Circuit Brkr</u> <u>es</u>	<u>Cable</u>	<u>M G's</u>	<u>Transformers &amp;</u> <u>Voltage Regulators</u>	<u>Electromagnetic</u> <u>Filters</u>
Allis-Chalmers	Anaconda	Bogue	G E	Teledyne Inet
FPE	Cyprus	Elec Mach	Hevi-Duty (Sola)	
GSE	Gen'l Cable	G E	Matra Elec	
I-T-E	G E	Katolight	Queensboro	
S & C Elec Co	ITT/Royal	Teledyne Inet	Superior Elec Co.	
Square D	Kerite Co	Westinghouse	Teledyne Crittenden	
Westinghouse	Okonite		Teledyne Inet	
	Westinghouse			

ALLIS-CHALMERS Switch Gear Division  
Post Office Box 2505  
West Allis, Wisconsin 53214

THE ANACONDA COMPANY  
Wire and Cable Division  
Greenwich Office Park 3  
Greenwich, Conn 06830

(203) 661-0090

BOGUE ELECTRIC MANUFACTURING CO.  
Patterson, New Jersey 07509

(201) 525-2200  
Mr. Kenneth Biber, Marketing Mgr.

CYPRUS WIRE & CABLE CO.  
2937 South Tanager Avenue  
Los Angeles, CA 90040

(213) 726-6888  
Mr. Frank K. Duerst, District Mgr.

ELECTRIC MACHINERY MANUFACTURING CO.  
800 Central Avenue  
Minneapolis, Minn 55413

FEDERAL PACIFIC ELECTRIC CO  
3323 San Fernando Road  
Los Angeles, CA 90065

(213) 254-3961  
Robert J. Drejer, Sales Engineer

GENERAL CABLE CORPORATION  
500 West Putnam Avenue  
Greenwich, Conn 06830

(203) 661-0100

GENERAL ELECTRIC COMPANY  
P. O. Box 2830  
Los Angeles, CA 90051

Mr. John Roberts, System Engineer

HEVI-DUTY ELECTRIC DIV  
Sola Basic Industries  
P O Box 268  
Goldsboro NC 27530

(919) 734 8900  
R. L. Cornella, VP Mktg.

I-T-E IMPERIAL CORPORATION  
P. O. Box 651  
Downey, CA 90241

Mr. Ron Tadman, Sales Engineer

ITT ROYAL ELECTRIC DIVISION  
95 Grand Avenue  
Pawtucket, R.I. 02862

(401) 722-8600  
Ralph Anderson, Regional Sales &  
Application Engineering

KATOLIGHT CORP  
3201 Third Avenue N. (POBox 939)  
Mankato MN 56001

(507) 387-7973  
Carl Buhr, Sales Manager

KERITE COMPANY  
A Subs. of Harvey Hubbell, Inc.  
49 Day St.  
Seymour, Conn 06483

(203) 888 2591

MATRA ELECTRIC INC.  
2453 E. Del Amo Blvd  
Compton, CA 90220

(213) 537 4690  
Ken Peugeot

OKONITE COMPANY  
237 Harbor Way  
South San Francisco CA 94080

(415) 589-2362  
Thomas A. Kommers

QUEENSBORO TRANSFORMER & MACHINERY CO.  
Designers and Manufacturers of Power  
Transformers  
115-25 Fifteenth Avenue  
College Point, New York 11356

S & C ELECTRIC COMPANY  
6601 Ridge Boulevard  
Chicago, Ill 60626

SQUARE D COMPANY  
Box 2115  
Los Angeles, CA 90051

Mr. Robert O'Brien

SUPERIOR SWITCHBOARD & DEVICES  
Div. of Union Metal Mfg. Co.  
Box 590  
Canton, Ohio 44701

(216\_ 452-4681

TELEDYNE CRITTENDEN  
13011 S. Spring Street  
Los Angeles, CA 90061

(213) 321-4355

TELEDYNE INET  
711 West Knox Street  
Gardena, CA 90248

(213) 327-0913  
Jim Vallely, Product Mgr/Power Conver-  
sion Equipment

WESTINGHOUSE ELECTRIC CORP  
9095 Telstar Avenue  
El Monte, CA 91731

Mr. Phil Bielsky

## MOTOR GENERATOR SETS

60/400 HZ

GENERAL. Motor generator sets are required to convert 60 Hz, 3-phase, 480 VAC nominal power to 400 Hz, 3-phase, 4160 VAC power. The motor generator set may utilize a step-up transformer, if required to convert low voltage 400 Hz power to 4160 VAC. However, if a transformer is required, it shall be the responsibility of the motor generator set manufacturer to supply it and all interconnections between the motor generator set and the step-up transformer.

The motor generator set/transformer combination must be supplied by a manufacturer with substantial experience in the manufacture of 60/400 Hz, synchronous type motor generator sets in the required power capacities. Motor generator sets shall meet the requirements of MIL-M-4803.

Power requirements will be in the range of 100 to 500 KVA.

The motor generator sets shall be parallelable under load, with up to four units operating in parallel to provide the needed load capacity and redundancy. Each motor generator set must be provided with automatic disconnect means whereby in the event that one of the motor generator sets connected to the common load bus should fault, the faulted unit will disconnect from the common bus without exceeding the specified output limits of voltage or frequency transient on the common load bus.

### INPUT POWER CHARACTERISTICS.

Voltage	480 VAC, $\pm 10\%$ , 3-phase, 3-wire.
Frequency	60 HZ $\pm 5\%$ .
Power Factor	0.90 minimum at full load.
Efficiency	85% minimum.
Inrush during startup	Not to exceed 150% of full load operating current.

#### OUTPUT POWER CHARACTERISTICS,

Nominal Load	150, 300, 500 KVA,
Voltage	2400/4160 VAC, nominal,
Phases	3-phase, 4-wire,
Frequency, steady state	400/60 times input frequency.
Voltage Tolerance	$\pm 0.5\%$ max.
Voltage Adjust Range	$\pm 10\%$ minimum.
Line Drop Compensation	
a. Resistive	0-5% adjustable
b. Reactive	0-5% adjustable
Voltage Transient	10% for 50% load step at 0.8 power factor.
Voltage Transient Recovery	100 ms max recovery time to within 98 to 102% of steady-state voltage.
Frequency Transient	$\pm 2\%$ for 50% load step.
Harmonic Voltage	2% RMS maximum. 1% max single harmonic.

The motor generator sets, and related controls must be designed to provide long life, excellent reliability and maintainability. The reliability target is 60,000 hours MTBF and an on-line availability of 0.9995. Scheduled service intervals cannot be more than once per year.

Submit a one-line diagram illustrating the power circuit you propose, and the paralleling of the system under load. Describe the start-up circuit. Describe the regulator. Include data on sizes, weight and efficiency.

QUESTIONNAIRE 60/400 HZ MOTOR GENERATOR SETS

1. How many years in motor generator business? \_\_\_\_\_
2. How many employees? \_\_\_\_\_
3. Do you manufacture 60/400 Hz Motor generator sets? \_\_\_\_\_
4. In what power capacities? \_\_\_\_\_
5. Have you manufactured sets per MIL-M-4803? \_\_\_\_\_
6. Do you operate under MIL-Q-9858A? \_\_\_\_\_
7. Have you manufactured 60/400 Hz motor generator sets, parallelable under load? \_\_\_\_\_
8. Have you manufactured motor generator sets operating at 4160 VAC either input or output? \_\_\_\_\_
9. Question #8, what power? \_\_\_\_\_
10. Question #8, 4160 VAC, 400 Hz output? \_\_\_\_\_
11. Question #10, how many years experience? \_\_\_\_\_

We will appreciate a customer list illustrating motor generator set systems you have manufactured which are similar to those required in power rating, output frequency, input and output voltage.

#### HV POWER CABLE REQUIREMENTS

400 Hz, 3-phase, 3-wire, 4160 VAC power distribution systems are being planned. Use of 3-wire shielded, twisted power cable, rated for 5 KV is planned. The shielding is required to minimize transmission of 400 Hz telephonic noise. The cable is twisted to minimize telephonic noise transmission and to maintain a close conductor configuration to minimize voltage drops due to power cable inductance. The power cable will have some distances in aerial spans, some distances in conduit, some sections in armored cable, or flexible conduit, and some sections in direct burial.

Different insulation types may be required for these different wire environments. Please advise on this.

#### QUESTIONNAIRES 5 KV, POWER CABLE

1. 5 KV rated power wire. In distribution of 3-phase, 400 Hz, 4160 VAC power, what derating factors are required as compared to distribution of 60 Hz power?
  - a. What derating factor is advised for voltage?
  - b. What derating factor is advised for current?
2. What composition and trade name insulation of wire is recommended for 400 Hz, 3-phase, 4160 VAC power distribution?
  - a. In conduit?
  - b. Direct burial?
  - c. Overhead?
  - d. Interlocked cable?

Please give reason for recommendations.

3. How much experience time have you had with each of the compositions and wire types recommended?
4. Are there any special precautions to be followed in terminations of 400 Hz power cable, as compared to 60 Hz power? Please provide the specification you would advise be placed in the contractor's specification regarding terminations.

SPECIFICATION OUTLINE  
TRANSFORMER / REGULATORS

It is intended that a single manufacturer will be responsible for the 3-phase, 400 Hz step-down distribution power transformer, the voltage regulators, and controls and protective switchgear, for transformation of 400 Hz, 4160 VAC, 3-phase power to 115/200 VAC regulated low voltage power for the aircraft load.

1. Power Transformer. The power transformer shall have a 3-phase, 3-wire delta primary winding set, and a 3-phase wye connected, 4-wire secondary winding set.
2. Input voltage is nominal 4160 VAC, 3-wire, 3-phase, 400 Hz. Secondary voltage is nominal 115/200 VAC. Actual turns ratio be exactly 35:1 primary to secondary.
3. Six ratings of transformers will be required with secondary load ratings of:
  - a. 30 KVA.
  - b. 60 KVA.
  - c. 90 KVA.
  - d. 150 KVA.
  - e. 300 KVA.
  - f. 400 KVA.
4. Transformers shall be provided with a shield of sheet copper between primary and secondary windings. The shield shall be grounded to the core.
5. Primary impedance of the transformer shall be a maximum of 0.6% for resistive loads and a maximum of 3% for reactive loads, for 100% of rated load current, at 400 Hz and with all secondary windings short circuited at 25° C.
6. Maximum temperature rise shall be 80° C.
7. Insulation shall be Class H in accordance with MIL-E-917.
8. The primary insulation shall be adequate to withstand a high potential test of 60 Hz voltage windings to winding and to ground, and to shield of 15,000 volts for 60 seconds. Primary insulation shall withstand an impulse test of 50,000 volts for 50 microseconds duration to ground and to shield.
9. The secondary winding shall withstand a high potential test of 4,000 volts, 60 Hz winding to shield and winding to ground.
10. Winding to ground insulation type shall be in accordance with MIL-E-917 requirements for Class H transformers.

11. Transformer tests shall include;

- a. Temperature rise at rated load.
- b. Impedance tests with secondary shorted.
- c. High potential tests, primary and secondary windings.
- d. Impulse test primary windings.

12. Transformer cabinet construction shall be steel with provisions for forklifting and for lifting.

13. The construction shall be for indoor or outdoor installation.

14. The transformer cabinet shall include a separate steel enclosed compartment which shall contain a fused oil cut-out switch with properly rated fuses and with adequate space for an installation contractor to make connections from the 4160 VAC power line to the fused oil switch. Fuses shall be readily accessible, and located for safe changing by maintenance personnel.

15. The transformer cabinet shall also be provided with a separate steel enclosure which shall contain a molded case circuit breaker, connected into the output circuit and rated to permit rated output current, and to protect the transformer from overloads. The compartment shall have adequate space for connections of the low voltage 400 Hz power distribution wire to the circuit breaker.

16. The cabinet paint shall provide protection against humidity and salt fog as found in U.S. coastal regions.

## VOLTAGE REGULATOR

The 400 Hz voltage regulators will be used to meet requirements of MIL-STD-704B. The voltage drop in the distribution system, which includes the 4160 VAC power line, the distribution transformers, and the low voltage power distribution and load cables, will cause up to 5% drop in voltage under worst case loads. MIL-STD-704B requires maintenance of a maximum voltage range of 116 to 119 VAC. This range includes voltage variations from all causes between the 400 Hz generator, and the power plug at the aircraft. MIL-STD-704B also limits voltage transient recovery time to 80 milliseconds. The specification for the voltage regulators will include requirements as follows:

1. The voltage regulators shall provide a boost in AC voltage of between 0 and 5% under full rated load, when connected to the output of the 400 Hz distribution transformers.
2. The power ratings of the 400 Hz voltage regulators shall correspond to the power ratings of the transformers.
3. Response time shall be less than 80 milliseconds for maximum excursions of voltages in response to voltage sensing signals.
4. The sensing circuit shall provide for boost in output voltage versus load, which can be adjusted to correspond to power factor of the load, to thereby provide accurate voltage boost versus load current characteristics. Range shall be 0 to 5% for either resistive or reactive loads or combinations of resistive and reactive loads.
5. The impedance of the voltage regulator shall be less than 1%.
6. The harmonic insertion shall be less than 0.25% at any load or voltage boost condition of the regulator within its ratings.
7. Each phase of 400 Hz AC output voltage shall be individually sensed and regulated.
8. Steps of AC voltage output shall be less than 0.25%.
9. The voltage regulator shall be convection cooled, with an efficiency above 0.99.
10. Regulators shall utilize Class H insulation per MIL-E-917 and shall operate at 80° C rise maximum at full load.
11. Windings shall withstand 4000 VAC, 60 Hz test potential to ground and to adjacent windings.
12. The housing shall be steel, weatherproofed, for indoor or outdoor mounting protected with paint to withstand high humidity and salt fog as experienced in coastal regions.

QUESTIONNAIRE TRANSFORMER/REGULATORS

1. How many years in transformer business? \_\_\_\_\_
2. How many years in AC regulator business? \_\_\_\_\_
3. How many employees? \_\_\_\_\_
4. Do you manufacture 400 Hz transformers? \_\_\_\_\_
5. Do you manufacture 400 Hz AC regulators? \_\_\_\_\_
6. In what power capacities? \_\_\_\_\_
7. Do you operate under MIL-Q-9858A? \_\_\_\_\_

We will appreciate a customer list illustrating transformers or voltage regulators you have manufactured which are similar to those required in power rating, frequency of output, voltage of input or output.

## LINE DROP COMPENSATORS

1. Line drop compensators are intended to compensate for the inductive impedance voltage drops in power distribution lines, transformers and load cables, and thereby to improve the voltage regulation at the load. Line drop compensators shall utilize only passive components, and shall provide correction independent from power factor or magnitude of the load circuits within their continuous rating.
2. Line drop compensators shall have the following ratings:
  - a. Type I - 75 KVA, 120/208 VAC, 400 Hz, 3-phase, 4-wire.
  - b. Type II - 150 KVA, 120/208 VAC, 400 Hz, 3-phase, 4-wire.
  - c. Type III - 400 KVA, 4160 VAC, 400 Hz, 3-phase, 3-wire.
3. The correction voltage range shall be a minimum of 15 percent of the design voltage, and shall be adjustable in 3 percent steps.
4. The units shall be able to withstand a short circuit current of 500 percent for 10 seconds without exceeding the voltage rating of any capacitors. They shall operate within component temperature limits with a 40° C ambient and a continuous overload of 125 percent of rated load.
5. Oil capacitors shall be operated at a maximum of 10 percent of their continuous KVA rating and not more than 35 percent of either their voltage or current ratings.
6. The reliability shall be a minimum of 50,000 hours MTBF by calculation using MIL Handbook 217B.
7. Dimensions shall permit installation in the space provided in the corresponding KVA rating of 400 Hz power.
8. Convection cooling shall be provided, without use of blowers.
9. The units shall accept high potential to ground testing at five times operating voltage throughout the electrical power circuits using 60 Hz test potential.
10. A double induced voltage test shall show no evidence of electrical corona.
11. Testing shall be required to demonstrate that the equipment meets all electrical requirements.
12. The manufacturer will be required to submit a test procedure, acceptable to a Government designated agency. A test report will be required prior to acceptance.

## APPENDIX 'M'

### SUMMARY OF RESPONSES TO JB & B QUESTIONNAIRE BY POTENTIAL SUPPLIERS OF 400 HZ EQUIPMENT

A number of manufacturers were contacted in writing with letter dated June 18, 1976. Due to poor response, a second letter with outline specifications requesting information on various products dated August 11, 1976, was mailed to a number of manufacturers.

The response to the August 11th. letter was better than the response to the first letter. However, even this second letter was not answered by many of the manufacturers who were contacted.

The various products were divided into four (4) major groups:

- (1) Switchgear, circuit breakers, fuses.
- (2) Cable: 600V and below; 5 KV
- (3) Motor generators.
- (4) Transformers and voltage regulators.

(1) Switchgear, Circuit Breakers, Fuses

<u>Mfg. Name</u>	<u>Response</u>	<u>Description</u>
Allis-Chalmers	No	-
FPE	No	-
GE	Yes	Letter dated October 5, 1976
ITE	No	-
ITT Jennings	Yes	Cat. No. IJ203A
S & C	No	-
Square D	No	-
Westinghouse	Yes	Letter dated 9/12/76 (irrelevant - concerns 75 KVA motor generators for computer applications)

Notes

1.0 GE Co. has submitted the following comments concerning derating factors:

Low Voltage Switchgear:	$60 \text{ Hz Amps} \times 0.55 = 400 \text{ Hz Amps}$
Low Voltage Switchboards:	$60 \text{ Hz Amps} \times 0.85 = 400 \text{ Hz Amps}$
2.4 KV to 13.8 Metalclad	
Switchgear:	$60 \text{ Hz Amps} \times 0.50 = 400 \text{ Hz Amps}$
Fused Cutouts:	$50 \text{ Hz Amps} \times 0.50 = 400 \text{ Hz Amps}$
Molded Case Circuit Breakers	
and Fused Switches:	$60 \text{ Hz} \times 0.85 = 400 \text{ Hz Amps}$

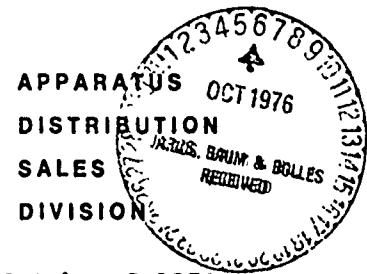
2.0 ITE Jennings has submitted the following comments:

Vacuum contactors may be used for control of 400 Hz circuits in lieu of circuit breakers or fused switches. Main advantages of contactors operating within a vacuum are as follows:

- Reliable operating mechanism
- No contact maintenance
- Long life
- Safety
- Compactness

# GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, 9350 E. FLAIR DRIVE, EL MONTE, CALIFORNIA 91734  
Phone (213) 572-5200  
MAILING ADDRESS: P.O. BOX 2830, TERMINAL ANNEX, LOS ANGELES, CALIFORNIA 90051



October 5, 1976

Mr. Paul Katzaroff  
Jaros, Baum & Bolles, Consulting Engineers  
1052 West 6th Street  
Los Angeles, California 90017

Subject: Equipment available from General Electric Company for  
operation at 60/400 HZ.

Dear Paul:

I am sorry that the accumulation of 400 Hertz equipment has taken  
so long.

The General Electric Company has a complete line of 60 Hertz  
electrical equipment; however, 400 Hertz equipment is special, or  
not available, from many of our product departments. It is hard to  
build a business unless there is an available market for the end  
product. I have found that our Transformer and Large Motor & Generator  
Departments do not see enough of this equipment to set up special  
designs for 400 Hertz. If the available shows up in the future, I  
feel we will take a new look to determine whether or not we wish to  
participate in this market.

In order to give you an answer to some of your questions, I wish to  
list the following per your 6/18/76 letter:

1. Motor - Generator Sets 60 - 400 Hertz:

We have Motor Generator sets available at 60 HZ; however,  
400 HZ. is a special and we have withdrawn from the 4160 volt.  
At the present time, we have a 75 KVA 60-415 Hz. package  
available for computer applications. Should you require 400  
Hz. exactly, this would be a special.

2. 400 Hz. Transformers:

We do not have a 400 HZ. transformer design above 10 KVA and  
this is in the low voltage class 480 volts.

3.(a) Molded Case Breakers and Fused Switches:

60 HZ. current rating  $\times .85 = 400$  HZ. current rating.

(b) Low Voltage Switchgear:

60 HZ. amps  $\times .55 = 400$  HZ. amps.

(c) Low Voltage Switchboards:

60 HZ. amps  $\times .85 = 400$  HZ. amps.

(d) 2.4 KV - 13.8 Metalclad Switchgear:

60 HZ. amps  $\times .50 = 400$  HZ. amps

On H.V. Switchgear, the relaying cannot be too expensive at 400 HZ. It may be necessary to rectify the short-circuit current output from CT's by means of a diode rectifier and use D.C. instantaneous relays.

4. Fused Cutouts:

60 HZ. amps  $\times .50 = 400$  HZ. amps.

5. 5 KV & 480 Volt Cable:

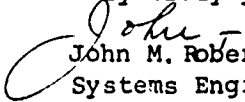
See attached cable fact letter.

Paul, from my discussion with various people in the General Electric Company, I find that we do not specialize in 400 HZ. equipment. For this reason, it has been difficult for me to give you a reply which may be of much help to you.

I understand that there are several companies who specialize in 400 HZ. equipment designed to MIL specifications.

I hope this small amount of information I am giving you will be of some help to you in your study.

Very truly yours,

  
John M. Roberts  
Systems Engineer

gt

Attachment:

Cable Facts, Feb. 1957



WIRE AND CABLE DEPARTMENT... BRIDGEPORT 2, CONNECTICUT



B. J. MULVEY  
G-E WIRE AND CABLE  
APPLICATION ENGINEER

B. J. Mulvey, G-E Wire and Cable Application Engineer, has had considerable experience dealing with wire and cable applications for high frequency power systems. We thought you'd be interested in the following explanation of the effects higher frequencies have on wire and cable.

February 1957

In general, 3-phase, 400-cycle power systems are designed in the same way that 60-cycle systems are designed, keeping in mind that the increased frequency will increase the skin and proximity effects on the conductors, thereby increasing the effective copper resistance. For a given current, this increase in resistance results in an increased heating and may require additional copper. The increased frequency will also increase the reactance, and this combined with the increased resistance will increase the voltage drop. The higher frequency will also increase the effect of magnetic materials upon cable reactance and heating. For this reason the cables should not be installed in steel or magnetic conduit or run along on magnetic structures in the building, etc.

The curves on the other side of this sheet show the AC/DC resistance ratio which would exist on a 400-cycle system and the resulting reduction in current rating which would be necessary from a heating standpoint to counteract the effect of the increased frequency.

The reactance can be taken as directly proportional to the frequency without introducing any appreciable errors. This method of determining reactance does not take into account the reduction due to proximity effect, but this change is not large and the error introduced by neglecting it is small.

The curves were drawn up for rubber or Flamenol cable but will be equally applicable to any 600 volt single conductor cable in the same non-magnetic conduit, or to interlocked armor cable with aluminum or bronze armor.

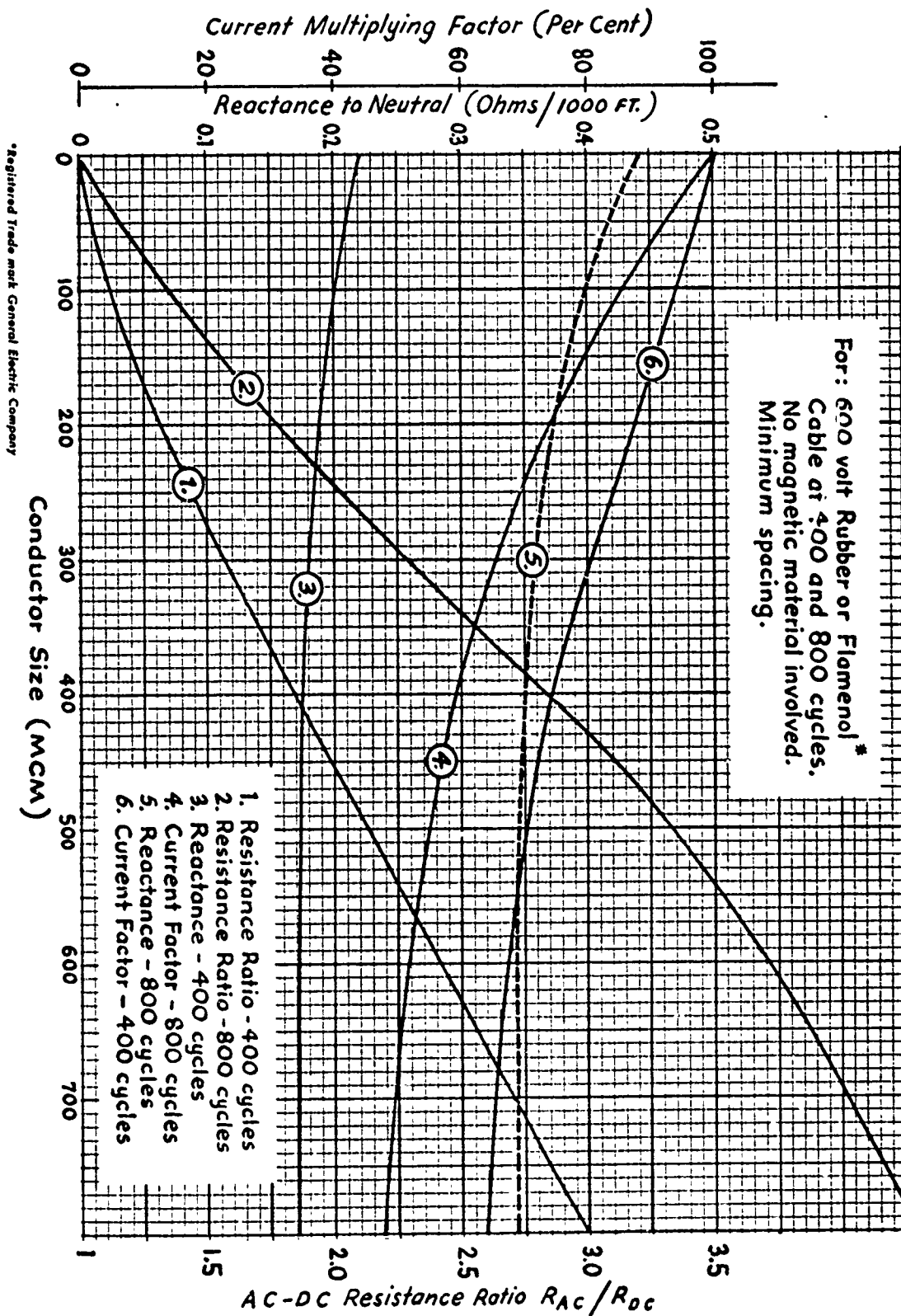
I believe this curve sheet together with the usual 60-cycle current carrying capacity tables which are available from many sources will give the user all the information he requires at this time.

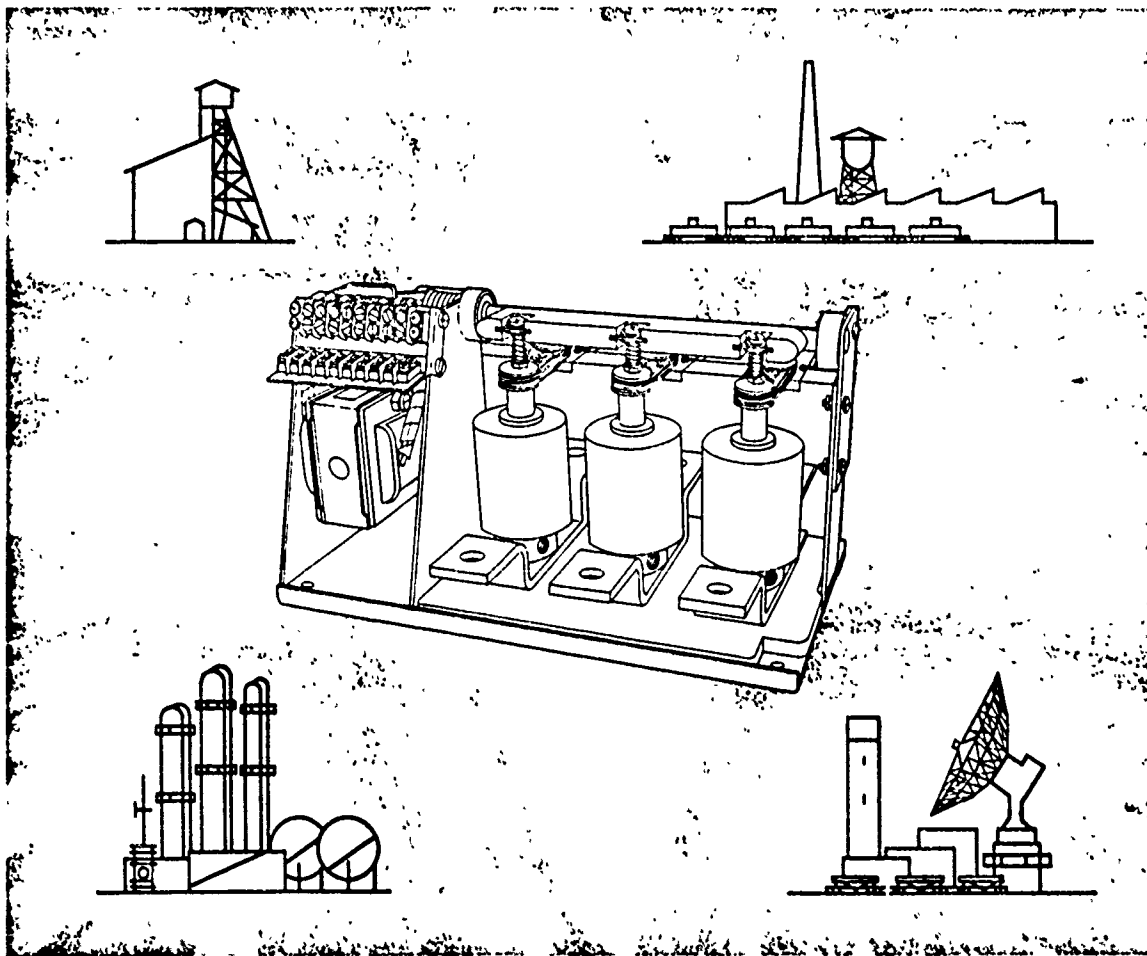
Where voltage drop is the limiting factor, the usual procedure is to parallel small conductors. This is often also done with larger current ratings.

(over)

*Progress Is Our Most Important Product*

GENERAL  ELECTRIC





## VACUUM CONTACTORS

**ITT JENNINGS**

# vacuum contactors

ITT Jennings vacuum contactors offer one of the most reliable means available for remotely controlling electric power.

Composed of a vacuum interrupter and an actuator linked together by an insulated actuating rod, they provide all of the operating advantages of a vacuum interrupting medium plus the benefits of a matching actuator — solenoid, motor or air — to meet specific application requirements.

Linkage and standoff posts which isolate the high voltage from ground are composed of epoxy glass laminate for DC or low frequency applications and silicone glass laminate for rf switching. Heavy duty connectors are provided for the high voltage connection. Most vacuum contactors also have two SPDT switches as auxiliary contacts.

## VACUUM CONTACTOR ADVANTAGES

ITT Jennings has adapted their proven vacuum interrupters for contactor use in order to offer the reliable, no-maintenance features of this unit for industrial motor control and other systems operating at a wide range of currents and voltages. Specifically, the operation of contacts within a vacuum offers such inherent advantages as:

1. *No Contact Maintenance* — Contacts are sealed within a very high vacuum and remain clean permanently. There is no contact oxidation or possibility of foreign matter forming on the contacts and leaving contaminating residues.

2. *Long Life* — The arc that results as the contact is made or broken is quickly extinguished within a vacuum. The special contact material used erodes at an extremely slow rate to provide reliable operation for tens of thousands of operations.

3. *Environmental Safety Factor* — Vacuum contactors are being used in environments involving corrosive atmospheres because there is no exposed contactor arcing.

4. *Compact, Reliable Operating Mechanism* — The high dielectric strength of a vacuum minimizes the contact-to-contact gap required to interrupt current, even at high voltage, high current levels for which some ITT Jennings contactors are designed. This short contact stroke not only provides high operating speed but also reduces the size and weight of the operating mechanism used. Mechanical life of ITT Jennings vacuum contactors range from 50,000 to more than a million operations, depending upon the device.

5. *Eliminates Arc Chute Replacement* — Ordinary air break contactors require fragile arc chutes to extinguish the arc that forms when the contact is broken. Arc chutes are damaged with use and ultimately require replacement. The manner in which vacuum contactors operate causes the arc to be extinguished rapidly without any damage or wear.

6. *Proven Operation* — ITT Jennings has been supplying vacuum interrupters for several decades for use in electrical power generation and distribution systems operating at all voltage levels. The long life and reliability of these devices

is such that many of the original units are still in operation, and their acceptance has increased with each year.

7. *Low Contact Resistance* — remains low and stable for the life of the contactor.

## APPLICATION NOTES

ITT Jennings vacuum power contactors are used for controlling dc, 50, 60, and 400-cycle circuits and other frequencies up to and including RF at all voltage levels. Their principal use is in high power electronic equipment, but some of the unique advantages of switching in a vacuum make them useful in many industrial applications. Many kinds of test, production, or processing equipment have requirements for long contact life without maintenance, for low cost high voltage control, or for sealed contacts because of difficult environmental requirements. Vacuum interrupters are inherently suited for these types of applications and are finding many new fields of usefulness due to recent advances in vacuum interrupter technology and the availability of new low cost units.

ITT Jennings vacuum interrupters are sold without actuating mechanisms to switchgear manufacturers who market them in high voltage load break switchgear, in circuit breakers, and in high capacity motor starters. Our line of solenoid actuated vacuum contactors are designed primarily for the electronics OEM market and for some industrial applications with severe service requirements that are not easily met by conventional NEMA rated equipment.

## AC SWITCHING AT POWER FREQUENCIES

The most common power frequency applications for ITT Jennings vacuum contactors are for switching and protecting the power transformers used in dc power supplies or in processing equipment with severe duty requirements. Most transformer switching is done on the primary side for off-on control, or to switch out current limiting resistors or reactors used for reduced voltage starting of power tubes. It may be necessary to use additional backup fault protection to take care of primary line side faults. This is sometimes accomplished by using a current limiting fuse or coordinating with a high capacity system breaker already located in the primary side. However, where frequent faults are anticipated, vacuum contactors offer a much longer life with no contact maintenance and they are often less expensive.

## HIGH VOLTAGE OVERCURRENT RELAYS

It is often better to sense overcurrents in the high voltage secondaries or in the dc line since the overcurrent relay can then be adjusted closer to the normal operating current without allowing for transformer inrush current (which may be 10 to 20 times normal line current). ITT Jennings high voltage overcurrent relays are designed to operate with this contactor line and are well suited to sensing in high voltage circuits.

## VOLTAGE TRANSIENTS

Voltage transients due to chopping have become a relatively minor consideration because of the improved interrupter design. In the small percentage of cases where a chopping problem may exist, the circuit can be designed to overcome the problem. For a high-voltage transformer where switching is performed in the low voltage primary, non-linear resistors; e.g., thyrite resistor, ZnO, etc., can be connected across the load. For switching in the high voltage secondaries, a more inductive circuit, RC filtering is recommended. RC protection consists of 0.12 to 0.5 mfd in series with 20 ohms per KV across each transformer winding. In wye connected transformers, suppression should be from line to neutral.

For further information about voltage transients, refer to the ITT Jennings catalog on Interrupters.

## RATINGS

**AC Voltage Ratings** — Test voltages for power equipment are given in volts RMS whereas those for RF switches are given in volts peak due to common practice in those industries. In a circuit with a delta or ungrounded wye connected transformer the vacuum interrupter sees, under normal operating conditions, a maximum of 87% of the line voltage but with a grounded wye connected transformer it sees only line to neutral voltage (which is line-to-line voltage divided by  $\sqrt{3}$ ).

## AC CURRENT RATINGS

Continuous current, and maximum interrupting current ratings are all rms values and should all be considered in selecting the proper contactor. Continuous line current can be calculated by dividing the total three phase KVA by  $\sqrt{3}$  and then by the line to line voltage.

When maximum fault currents are calculated, consideration should be given to the fact that the first loops of current flow can always be asymmetrical (See Fig. 1) by as much as 2.7 times peak instantaneous value or 1.6 times RMS value of the steady state for the first loop. The asymmetry factor (RMS ratio) decays in most practical cases to almost the steady state value 1 in approximately 4 cycles (for more information contact ITT Jennings). Therefore the faster the contactor opens after initiation of the short circuit (consider sum of minimum tripping delay plus contact opening time) the higher the asymmetrical current it has to interrupt. Maximum interrupting currents used in the rating charts assume an asymmetry factor of 1.7.

(CONTINUED ON PAGE 10)

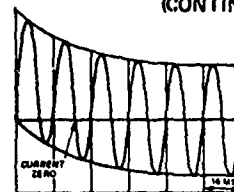


Fig. 1

## DESCRIPTION

This figure illustrates the construction of a solenoid-operated ITT Jennings vacuum contactor. The basic parts of the unit are the vacuum interrupter, the actuator (a solenoid in this case although motor driven and pneumatic units are available) and an insulated actuating rod linking the two units together.

The interrupter consists of an evacuated ceramic insulating envelope in which there are two contacts, one fixed and one movable. The movable contact is operated from the outside through a metallic bellows which provides a vacuum-tight seal.

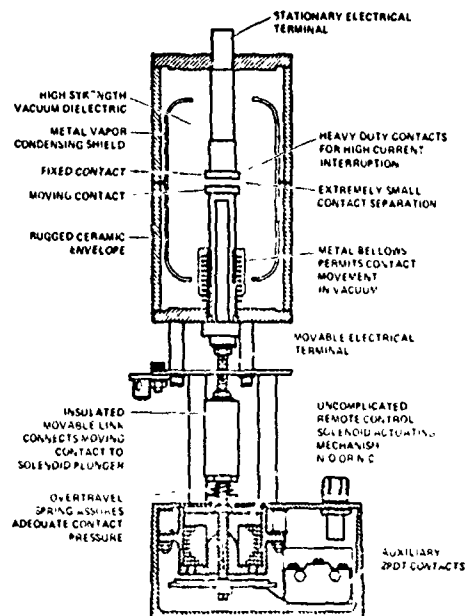
A vacuum has an extremely high dielectric strength — as high as 5000 volts per mil. When the contacts are opened to interrupt current flow, metal vapor is generated by the passage of current through the contacts. The vapor sustains the arc that is created, maintaining it down to or near current zero.

The small arc drawn on contact opening is quickly extinguished because there are no gases and there is only a small voltage drop across it. As the arc extinguishes, the metallic vapor rapidly diffuses outward and condenses on the cool surface of the vapor shields, which serve to prevent it from depositing on the ceramic insulating surfaces.

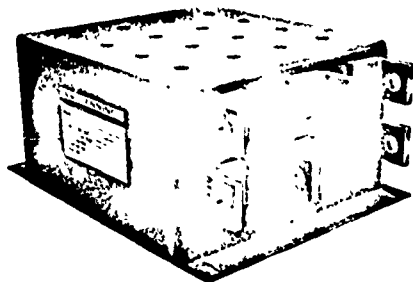
Fast arc extinction and rapid recovery of dielectric strength after contact opening are characteristics of vacuum interrupters.

A unique phenomenon with vacuum interrupters is auto-maintenance of the vacuum. The metallic ions released from the contacts provide a gettering action. Tests have shown that frequent operation of the contacts produces a steady improvement

in vacuum level because the released metallic ions actually remove gas molecules from the evacuated space. This ion-pumping action tends to maintain the vacuum near the high initial value.



# three pole vacuum contactors



## MODEL RP151B

A small, lightweight 3 phase, normally open, 200 amp vacuum contactor for use in equipment which requires a high speed interrupt time. It is useful as an overload interrupter to 2000 amps rms interrupting capacity. Special erosion resistant contacts offer long life without adjustment or contact maintenance at rated current of 200 amps. Typical test results indicate a minimum electrical load life of 250,000 operations.

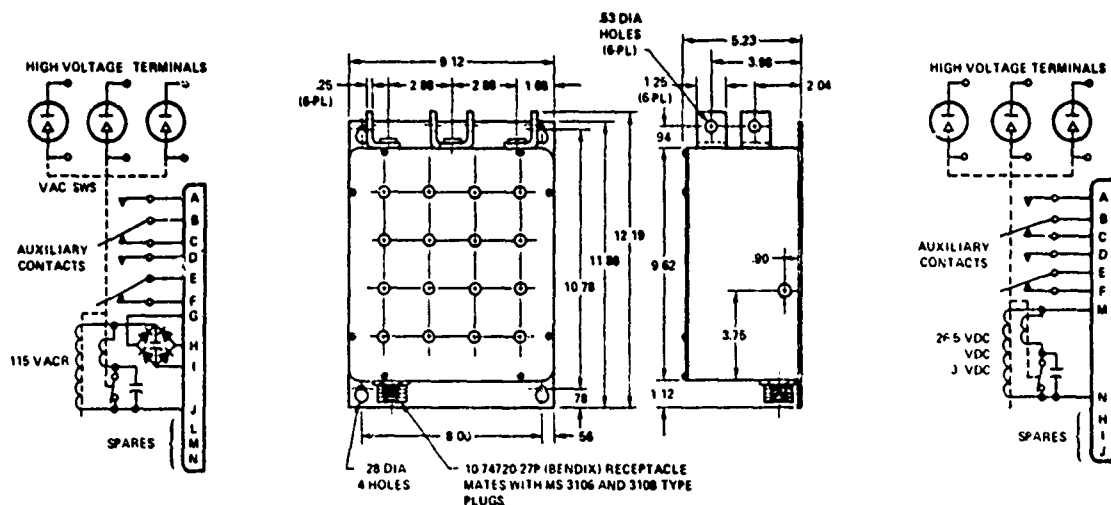
## GENERAL SPECIFICATIONS

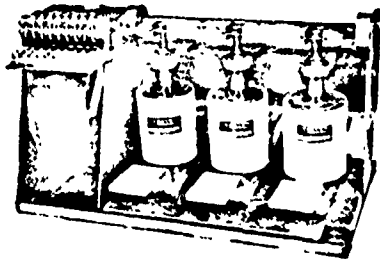
Rated Voltage	
Volts RMS	600
50/60/400 Hz	
Rated Continuous Current	
Amps Rms	200
Max. Interrupting Capability	
Current	2000
Amps Rms	
Load Life	
(Min.)	250,000
Interrupt	Less Than <sup>1</sup>
	1 cycle
Auxiliary	2SPDT
Contacts	230 VAC/10A
Weight	16 lbs

<sup>1</sup>Contact opening time 8 - 10 ms after DC Solenoid is deenergized.

## ACTUATOR SPECIFICATIONS

Model No.	Actuator Voltage	Pull-in Current Amps	Hold Current Amps
RP151B4541X44R20	26.5 VDC	2.8	.4
RP151B4541X45R20	48 VDC	1.3	.15
RP151B4541X46R20	100 VDC	.7	.09
RP151B4541X47R20	115 VACR 50/60/400 Hz	.7	.09





### MODEL RP155B

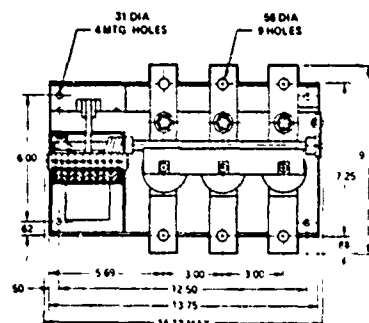
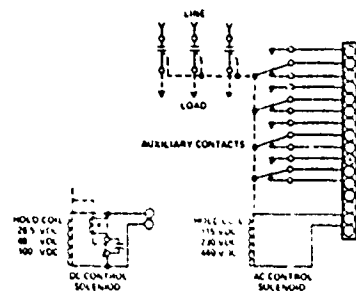
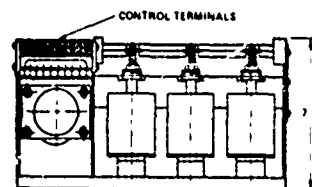
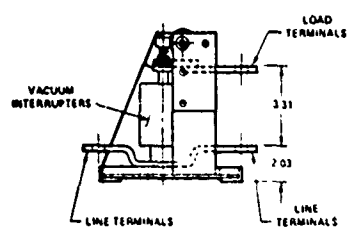
A small, lightweight 3 phase, normally open, 300 amp vacuum contactor for use in equipment which requires up to Nema size 5 contactors. It is useful as an overload interrupter to 3000 amps rms interrupting capacity. Special erosion resistant contacts offer long life without adjustment or contact maintenance at rated current of 300 amps. Typical test results indicate a minimum electrical load life of 250,000 operations.

### GENERAL SPECIFICATIONS

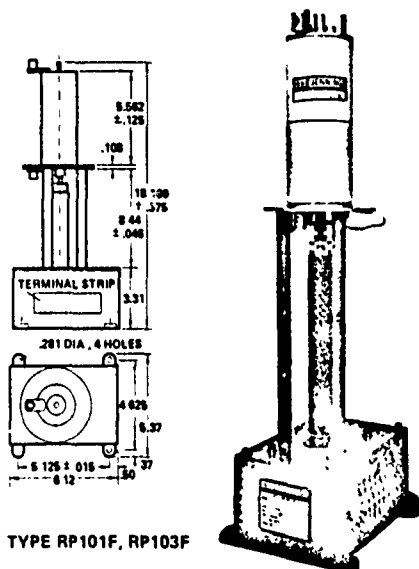
Rated Voltage	1500
Volts RMS	
50/60/400 Hz	
Rated Continuous Current	300
Amps Rms	
Max. Interrupting Capability	3000
Current	
Amps Rms	
Load Life	250,000
(Min.)	
Interrupt Time	Less Than
	2 cycles
Auxiliary	4 SPDT
Contacts	230 VAC/5A
Weight	25 lbs

### ACTUATOR SPECIFICATIONS

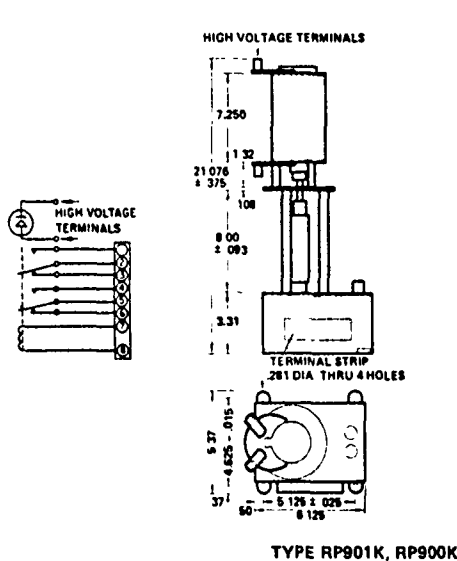
Model No.	Actuator Voltage	Pull-in Current Amps	Hold Current Amps	Mech. Life (Min)
RP155B4544X44TXO	26.5 VDC	16.5	1.65	$2.5 \times 10^5$
RP155B4544X45TXO	48 VDC	9	0.9	$2.5 \times 10^5$
RP155B4544X46TXO	100 VDC	4.3	0.4	$2.5 \times 10^5$
RP155B4549X41TXO (60 Hz)	115 VAC	22	1.9	$1.0 \times 10^6$
RP155B4549X4KTXO (50 Hz)				
RP155B4549X42TXO (60 Hz)	230 VAC	8.6	.83	$1.0 \times 10^6$
RP155B4549X4LTXO (50 Hz)				
RP155B4549X48TXO (60 Hz)	460 VAC	6.2	0.42	$1.0 \times 10^6$
RP155B4549X4MTXO (50 Hz)				



# high voltage alternating and direct current contactors



TYPE RP101F, RP103F



TYPE RP901K, RP900K

## GENERAL SPECIFICATIONS<sup>1</sup>

SERIES	RP101F	RP103F	RP901K	RP900K
Test Voltage (KV Peak)	50	50	70	70
Rated Voltage (KV Peak) <sup>2</sup>	30	30	50	50
Rated Continuous Current (Amps)	100 DC	100 RMS	100 DC	200 RMS
Max Interrupting Capability (Amps Rms)	—	2000	—	4000
Max. Interrupt DC Power (KW)	500 (10A Max.)	—	500 (10A Max.)	—
Capacitor Discharge Decaying to 0 in 200 $\mu$ s	—	50 K Amps	—	100 K Amps
Contact Resistance (Ohms Max.)	.0005	.0005	.0005	.0005
Contact Capacity (Pf)	4.5	4.5	5.5	5.5
Contact Inductance (nH)	32	32	45	45
Mechanical Life ( $1 \times 10^5$ )	1	1	1	1
Weight (Lbs.)	8-3/4	8-3/4	15	15
Auxiliary Contacts	2 SPDT	2 SPDT	2 SPDT	2 SPDT
Auxiliary Contact (Volts AC Rms)	230	230	230	230
Auxiliary Contact Current (Amps Rms)	15	15	15	15

<sup>1</sup>When ordering, select specific model from Actuator Specifications table.

<sup>2</sup>Derate to 15.5 kv rms for 50/60 cycle power.

## ACTUATOR SPECIFICATIONS

Model <sup>3</sup> Number	Contact Arrangement	Actuator Voltage (Volts)	Pull-in Current (Amps)	Hold Current (Amps)	Hold Power (Watts)	Time to Close, Typ. (Millisec)	Break Time, Typ. (Millisec)
RP101F4903D21B20	N/O	115	6.85	0.53	25	60	50
RP101F4904D21B20	N/C	60 Hz	RMS	RMS			
RP101F4304D26B20	N/C	100	0.7	0.09	10	55	42
		DC	DC	DC			
RP103F4903D21B20	N/O	115	6.85	0.53	25	60	50
RP103F4904D21B20	N/C	60 Hz	RMS	RMS			
RP103F4304D26B20	N/C	100	0.7	0.09	10	55	42
		DC	DC	DC			
RP901K4903D21B30	N/O	115	6.85	0.53	25	60	50
RP901K4904D21B30	N/C	60 Hz	RMS	RMS			
RP901K4601D26B30	N/O	100	3.75	0.2	20	34	11
RP901K4602D26B30	N/C	DC	DC	DC		27	17
RP900K4903D21B30	N/O	115	6.85	0.53	25	60	50
RP900K4904D21B30	N/C	60 Hz	RMS	RMS			
RP900K4601D26B30	N/O	100	3.75	0.2	20	34	11
RP900K4602D26B30	N/C	DC	DC	DC		27	17

<sup>3</sup> Change green number "1" to "2" if 230 volt 60 Hz actuation is desired. For 115 volt 50 Hz change number to "k". For 230 volt 50 Hz change number to "L". Specifications remain the same.

## high voltage overcurrent relays

Switching of high voltage dc circuits is one of the most challenging of all switching functions. To provide the switching speed necessary for such operations, ITT Jennings offers a line of highly sensitive overcurrent relays designed for extremely fast operation at high voltage levels.

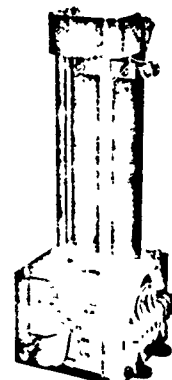
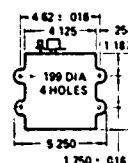
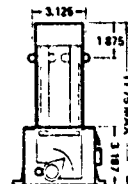
A rise in current in the high voltage line energizes the trip solenoid which is insulated from ground by 6" of NEMA Grade G11 epoxy glass laminate to handle voltages up to 75 kv. In turn, the trip solenoid actuates a SPDT switch mounted in the base of the unit via a lightweight insulating rod. This interlocking SPDT switch can be used to trigger operation of a separate ITT Jennings vacuum contactor to interrupt the overload current.

The overcurrent relay will operate in 4 ms maximum when a ten times overload is sensed. After the overcurrent relay is tripped, it must be reset with an enclosed 115 VAC solenoid before the main contactor can be energized.

The following sensing ranges are available \*

MODEL NUMBER	CURRENT RANGE
1. 4701D21HAO	2 to 1.0 amps dc
2. 4701D21HCO	1 to 5 amps dc
3. 4701D21HEO	3 to 15 amps dc
4. 4701D21HGO	10 to 50 amps dc

\*Special trip ranges available on request



# high voltage vacuum rf contactors

## RF SWITCHING

Vacuum contactors solenoid operated, air actuated, or motor driven have found wide application in all kinds of RF applications where unusually low and stable resistance is essential.

The use of a vacuum as a contact environment provides increased operating reliability and assures long contactor life. The absence of oxygen prevents corrosion and the formation of oxides and organic materials which could increase contact resistance. Low contact resistance is maintained even when high current causes overheating or arcing accidentally occurs.

The high dielectric strength of a vacuum and its very fast recovery after arcing is a feature which manifests itself in the small size of the vacuum contactor. Only a slight contact separation is required to withstand high voltages. The limited contact movement results in a very small contactor size because it permits the use of a small, simple actuating mechanism. This reduction in overall size makes available RF switchgear with low inductance and low capacitance.

## APPLICATIONS

The superior performance of vacuum contactors is commonly used in the MF and RF bands to handle currents ranging from 20 to several hundred amperes. Typical applications include band switching of transmitters, switching filter sections and antenna multicouplers, antenna reflector switching, tap changing of rf coils used in induction and dielectric heating RF generators and switching of transmission lines.

Vacuum RF switches are available without an actuator for use in custom designed tap changing filter network switching applications with a number of switches driven by cams on a common shaft.

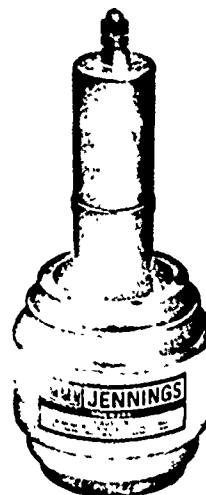
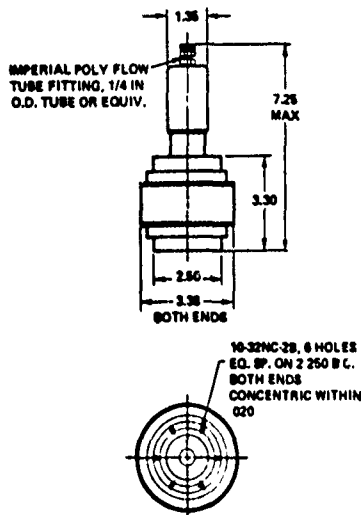
## SPECIFICATIONS

MODEL NO.	RP233X4513006MOO(grounded) RP233X4513C36MOO(insulated)	RF20B4319D31GOO	RP233D1585	RF20B1586
Operation	Solenoid	Motor	Air	Air
Test Voltage Peak KV @ 60 Hz	40	40	40	40
Operate Voltage <sup>1</sup> Peak KV @ 32 MHz	25	25	25	20
Continuous Current <sup>1</sup> Amps (RMS) @ 32 MHz	35	200	35	135
Contact Resistance Max. Ohms	0005	0004	.0005	0004
Contact Capacitance Pf	2	10	2	10
Contact Inductance Nh	25	25	25	25
Contact Arrangement	N/O	bi stable	N/O	N/O
Open Time Close Time	17 Ms Open 75 Ms Close	7 Sec.	Less Than 200 Ms	Less Than 200 Ms
Actuation	7 A Pull-in 09 A Hold at 100 VDC	11 A @ 115 VAC 60 Hz	40 ± 5 psig	35 ± 5 psig
Weight	3 Lbs. 3 Lbs 8 Oz	5 Lbs 6 Oz	12 Oz	2 Lbs 12 Oz
Mechanical Life	1 x 10 <sup>5</sup>	1 x 10 <sup>5</sup>	1 x 10 <sup>5</sup>	1 x 10 <sup>6</sup>
Auxiliary Contact Ratings Volt (Rms)/Current (Rms)	Form C 230/7	Form C 230/7	N/A	N/A

<sup>1</sup> Voltage and current rating will be greatly increased at lower frequencies

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The image contains two sets of technical drawings for a device, labeled "GROUNDED" and "INSULATED".

**GROUNDED:**

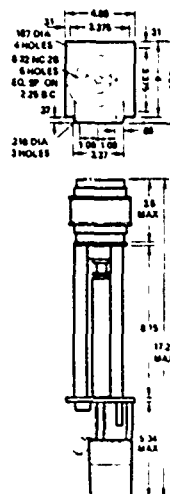
- Top View:** A square component with a circular center. Dimensions: 2.25 (width), 1.75 (height), .35 (corner radius), 1.750 (center-to-center distance), .25 (edge distance), and .25 (edge distance).
- Side View:** A vertical assembly. Dimensions: .812 (top section height), 1.312 (middle section height), 1.000 (bottom section height), and 3.5 (total height). A dashed line indicates the internal structure.

**INSULATED:**

- Top View:** A square component with a circular center. Dimensions: 2.25 (width), 1.750 (height), .35 (corner radius), 1.750 (center-to-center distance), .25 (edge distance), and .25 (edge distance).
- Side View:** A vertical assembly. Dimensions: 4.875 (top section height), 1.000 (middle section height), 1.000 (bottom section height), and 2.25 (total height). A dashed line indicates the internal structure.

Both drawings include a label "250 MA. AMOUNTING AND 1.000 IN. THERMAL PROTECT." and a "16NC 2" label on the side view.

This contactor is supplied with a motor drive that provides smooth, quiet, impact free operation. The drive has an over-running ball screw which allows it to run free after an open/close operation, thus eliminating the need for limit switches. The motor produces a maximum of 5.5 inch-pounds of torque and draws 0.1 amp at one inch-ounce of torque. In the event of power failure, the switch may be manually operated by turning the hex-shaped transition shaft.



# vacuum contactors (cont.)

## AC Current Ratings (cont. from page 3)

Maximum steady state fault current depends upon circuit impedance. In a primary bus fault the fault current is limited only by source impedance which may be 2% to 5% depending on the distance from the power source and the impedance of transformers and line in between. Primary bus faults can therefore be as high as 20 to 50 times rated KVA line current of source.

In calculating maximum short circuit currents due to faults in or beyond the transformer secondaries a knowledge of transformer impedance is necessary since a transformer with 5% impedance will limit the maximum fault current to a value of 20 times normal line current. Most transformers have impedance of less than 5% although source impedance and other impedances in the equipment being protected may increase the total impedance to as high as 10%.

Example - A typical 100 KVA three phase transformer in a dc power supply with 12 kv secondaries and 440 volt primaries would have rated KVA line currents of 131 amps rms in the primaries and 5 amps rms in the secondaries. If total circuit impedance is 8% (5% in the power supply transformer and 3% in the source and line) the maximum primary fault current due to a short circuit in the high voltage secondaries would be 1640 amps rms. If interruption occurred within two cycles of fault initiation this value could be offset by a factor as high as 1.2 times 1640 amps for a total fault current of 1970 amps rms. Of course most fault currents would be less than this value since maximum offset doesn't always occur and faults are often further on in the circuit where the impedance of rectifiers and other circuit components help limit the fault current to lower values. (Corresponding fault current in the high voltage secondaries is only 96 amps which is why the high voltage secondaries are often a desirable place for fault protection where a large number of fault operations are anticipated).

## DC SWITCHING

High voltage vacuum contactors can help the circuit designer solve complex dc switching problems which are difficult to handle. They can be used to interrupt high voltage, capacitive, resistive or inductive loads without the damaging electrical breakdown so frequently displayed by conventional dc switches.

Vacuum contactors are frequently used in charging capacitor banks, isolating charge banks, and safety grounding of power supplies. They are also being used to discharge high energy storage capacitors and for the generation of high current pulses for plasma study, shock waves and metal forming.

DC Switching of Pulse Networks - Vacuum contactors are rated in continuous DC amps. They are used in a broad range of high power radar systems where the peak current is considerably above the continuous current rating of the switch, but where the effective current may be within the switch rating. The effective current in a square wave pulse = the peak current  $\times \sqrt{\text{duty cycle}}$ . For example, a typical radar square wave pulse of 2,000 amps peak with a .01 duty cycle = 2,000 amps  $\times \sqrt{.01}$  = 200 DC amps effective which is within the continuous rating of most vacuum contacts.

DC Switching of Power Supplies - Vacuum contactors are used for switching current limiting reactors and resistors, switching DC power directly to tubes and modulator loads, interrupting DC currents, and isolating dc loads from one common power supply which feeds more than one load. They are also used for DC transfer switching.

In switching DC inductive loads suppression networks are required across the inductances when breaking the circuit and may be required when making the circuit to avoid possible overvoltages. At high voltages a 1/8 to 1 mfd capacitor in series with 1 ohm per KV makes an effective suppression network across an inductance. The suppression circuit should be critically damped.

DC Load Switching - In DC load switching, current zeros do not exist as in AC circuits. Extremely rapid arc extinction in vacuum switches due to the high velocity radial diffusion of vaporized metal permits vacuum switches to interrupt DC loads more effectively than other types of switchgear.

1. Vacuum switches are rated up to 20 amps at 30 KV DC and 10 amps at up to 50 KV DC switching resistive loads without arc suppression. (See Figure 2.)

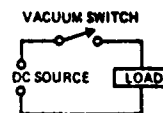


Fig. 2 - No Arc Suppression

2. Vacuum switches using an R-C suppression across the contacts can interrupt slightly higher currents with less arcing time which increases contact life. (See Figure 3.)

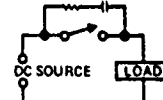


Fig. 3 - R-C Arc Suppression (1Ω/KV; 0.125-1 MFD)

3. Vacuum switches using a charged capacitor suppression circuit that causes ringing and creates artificial current zeros have been used to interrupt up to 35 KV DC at 150 amps DC resistive loads. (See Figure 4.)

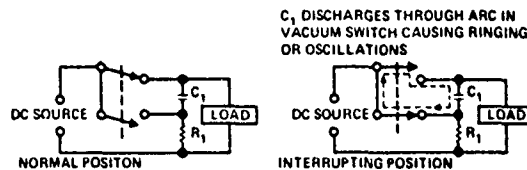


Fig. 4a

Fig. 4b

Fig. 4a - Charged Capacitor Suppression Circuit (Normal Position)

Fig. 4b - Charged Capacitor Suppression Circuit (Interrupting Position)

4. Inductive loads can be switched like resistive loads when a diode is used in parallel to the load. (See Figure 5.)

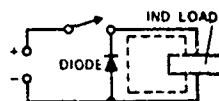


Fig. 5 - Inductive Load Switching

We suggest that high current DC interrupting applications be submitted to Jennings application department for review and recommendations.

## ITT JENNINGS WARRANTY POLICY

### A. Warranty

ITT warrants that at the time of shipment the products manufactured by ITT and sold hereunder will be free from defects in material and workmanship and will conform to the specifications furnished by or approved, in writing, by ITT.

### B. Warranty Adjustment

1. If any defect within this warranty appears, Purchaser shall notify Seller immediately.
2. ITT agrees to repair or furnish a replacement for, but not install, any product which, within one year from the date of shipment by ITT, shall, upon test and examination by ITT, prove defective within the above warranty.
3. No product will be accepted for return or replacement without the written authorization of ITT. Upon such authorization and in accordance with instructions by ITT, the product will be returned to ITT, shipping charges prepaid by Purchaser.

### C. Exclusions from Warranty

1. The foregoing warranty is in lieu of and excludes all other expressed or implied warranties of merchantability or fitness or otherwise.

2. ITT will not be liable for any special or consequential damages or for loss, damages or expense directly or indirectly arising from the use of the products or any inability to use them either separately or in combination with any other equipment or material or from any other cause.

3. The warranty does not extend to any product manufactured by ITT which has been subjected to misuse, neglect, accident, improper installation or to use in violation of instructions furnished by ITT.

4. The warranty does not extend to nor apply to any unit which has been repaired or altered at any place other than at an ITT factory by persons not expressly approved by ITT, nor to any unit, the serial number of which has been removed or defaced or changed.

5. This warranty applies to new equipment only and will cover repaired or replacement items only to the extent of the one year from the date of shipment of the original equipment noted above in paragraph B2.

## ORDERING INFORMATION

Complete Model No. (Including Actuator) \_\_\_\_\_  
Quantity: \_\_\_\_\_  
Application: \_\_\_\_\_  
Operating Conditions: \_\_\_\_\_  
Load: \_\_\_\_\_  
Special Requirements: \_\_\_\_\_

Unless otherwise specified on your order shipment will be made via most economical method. If a specific carrier is specified, shipment will be made at full valuation unless your order instructs differently. In case air shipment and full valuation are desired, please specify whether air express or air freight. Lacking specification full valuation will be used.

Normally all prices and quotations are F.O.B. San Jose, Calif. Terms are net 30 days.

Specifications subject to change.

## VACUUM CONTACTOR PATENTS

Vacuum Contactors made by ITT Jennings are manufactured under one or more of the following issued patents. Other patents are pending.

2740867	3014106	3148259
2740869	3021407	3166658
2740868	3026394	3178541
2794101	3035139	3178542
2794885	3042766	3189715
2832872	2966569	3196236
2863026	2979587	3190991
2863027	2979588	3145278
2906841	2981813	3187140
2920169	2982836	3218409

■ In addition to their years of experience building vacuum contactors ITT Jennings has acquired many exclusive processing techniques that assure superior performance. They have a qualified, experienced engineering staff plus complete high voltage laboratories for proper testing of vacuum contactors. If a new design or modification of a standard unit is necessary our quick-reaction laboratory can turn it out in a minimum of time. ■ For immediate help on your specific application fill out and mail us the handy postage paid reply card. We welcome the opportunity to be of service. ■

**ITT JENNINGS**

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**OTHER ITT JENNINGS PRODUCTS**

Vacuum Relays  
Vacuum Capacitors  
Vacuum Coaxial Relays  
Vacuum Interrupters  
Gas Capacitors  
AC & DC Digital Kilovoltmeters  
AC & DC Digital High Potential Testers  
Megohmmeters  
Film Capacitors  
Ceramic Capacitors

**JENNINGS DIVISION ,**

International Telephone and Telegraph Corporation  
970 Mc Laughlin Avenue  
San Jose, California 95116  
Phone: (408) 292 4025  
TWX: 910-338-0159

**ITT JENNINGS**

(2) Cable

<u>Mfr. Name</u>	<u>Response</u>	<u>Description</u>
Anaconda	No	-
Cyprus	Yes	Letter dated September 8, 1976
General Cable	No	-
GE	Yes	Letter dated October 8, 1976 - See Sec. (1)
ITT/Royal	Yes	Letter dated August 25, 1976
Kerite Co.	No	-
Okonite	Yes	Letter dated September 10, 1976
Westinghouse	No	-

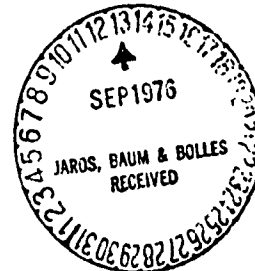
H.L. Rawlings, P.E.  
Manager, Engineering Services  
Western Region

Cyprus Wire & Cable Company

230 South Fifth West Street  
Salt Lake City, Utah 84101  
Telephone 801)364-3452

September 8, 1976

Jaros, Baum & Bolles  
Consulting Engineers  
1052 West 6th Street  
Los Angeles, California 90017



Attention: Mr. Paul Katzaroff

Gentlemen:

Your letter of August 11, 1976 addressed to our Los Angeles office has been referred here for answering. This letter concerns feasibility study for a centralized 60/400 HZ generation and distribution system. In your letter you ask 4 questions concerning the use of 5KV shielded power cables. The answers are as follows:

1. In distribution of 3 phase, 400 HZ, 4160 volts AC no derating factor is necessary for voltage. The cables are designed to withstand a given voltage whether it is DC or AC and regardless of the frequency AC. A derating factor is advised for current. We cannot give you any general recommendation as each individual installation requires a separate calculation based on the parameters involved. These calculations are quite involved and require a rigorous mathematical solution. So far as we know no simple approximations are available to make the solution easier. The calculations are based on mathematical formulas derived by Nehr-McGrath and take into consideration all pertinent factors of each individual installation. The solution of the Nehr-McGrath calculations lead to losses in each individual cable. Once these losses are known a suitable derating factor can be determined. Also it is necessary to pay particular attention to the voltage drop on these systems as it is much more severe than on ordinary 60 cycle distribution systems. More often than not the voltage drop on a given system will be the determining factor as to what conductor size is used instead of the losses in the system itself. Here again we cannot give you any simple methods for determining the voltage drop. Each individual installation must be calculated for the conditions present.

**CYPRUS**

September 8, 1976

2. This question asks what composition and trade name insulation of wire is recommended for 400 HZ 3 phase, 4160 volts AC power distribution. We would recommend the use of UL approved cable referred to in the 1975 National Electric Code as "MV-90, UL 1072 - Medium Voltage Solid-Dielectric Cables Rated 5 to 35 KV." I am attaching sheets 1 and 2 showing the construction of single or multi-conductor shielded cable with covering. These cables are satisfactory for use in conduit, direct burial and overhead. This type construction can also be incorporated in an aluminum interlocked armor cable. We would not recommend the use of galvanized steel as the losses would be much too high. I am attaching our data sheet #7160 giving additional information on this cable design and our data sheet #7485 showing an interlocked armor construction. Please note this sheet shows galvanized steel for which we would substitute aluminum. We can wholeheartedly recommend these constructions as being the most suitable available today. Based on our long years of cable manufacturing experience it is our belief these cables will give the best possible service for the conditions you have described.

3. You ask how much experience time we have had with each of the compositions and wire types recommended. Our experience with XLP cables goes back to approximately 1950. We were one of the very first in the industry and have a long history of millions of feet of this type construction in use all over the country. Our experience with EPR insulations dates back approximately 15 years. Here again we have a successful experience record with millions of feet of this construction in use. We have kept pace with the industry on both of these insulating materials and have as much experience as anyone in their use and manufacture.

4. You ask if there are any special precautions to be followed in terminations of 400 HZ power cable. All splices and terminations must be made with considerable care and attention to fine detail. It is very important to follow the manufacturers' instructions and make sure they are carried out to the letter. An experienced electrician should be used in all instances. If these simple precautions are followed there is no reason why satisfactory splices and terminations cannot be made on either 400 HZ or 60 HZ. As our interest is primarily cables we are not in the best position to write a specification for you for terminations. Rather, we suggest you contact someone such as Elastimold Division Amerace Corporation, Electro Products Division 3M Company or Bishop Electric. We have tested products from all three of these companies and find them to be quite satisfactory for your use on this application.

We trust the above information will be helpful to you. If you have other questions we would be happy to hear from you at any time. Thank you kindly for your interest in our products.

Yours very truly,



H. L. Rawlings  
Manager, Engineering Services  
Western Region

HLR:ah

Enc. 4

cc: F. K. Duerst,  
Cyprus-L.A.

**CYPRUS**

MV-90, UL 1072

Medium Voltage Solid Dielectric Cables Rated 5 to 35 kV

1. Single-Conductor Shielded Cables:

- a. Voltage Range: 5 to 35 kV
- b. Conductors: #8 AWG through 1000 MCM  
Copper - Conventional concentric lay or compressed stranded.  
Aluminum - Conventional concentric lay or compact or compressed stranded.
- c. Strand Shielding: Semiconducting tape or extruded layer.
- d. Insulation: XLP or EPR
- e. Shielding: 1) Semiconducting tape or PolyKote system or extruded layer.  
2) Helical bare or tin copper tape or helically-applied copper wires.
- f. Separator over shielding: (Optional) If used plain or corrugated mylar or asbestos-backed mylar.
- g. Jacket: PVC, Hypalon or Neoprene

MV-90, UL 1072

Medium Voltage Solid-Dielectric Cables Rated 5 to 35 kV.

2. Multi-conductor Shielded Cable with covering:

- a. Individual conductors same as single-conductor shielded cables described above (Item 1) except with or without the overall jacket.
- b. Ground Wires (Optional)
- c. Fillers: Required to make cable round, material optional, may be separate or integral.
- d. Assembly: Conductors cables with optional fillers and/or ground wires.
- e. Binder: Optional
- f. Covering: A jacket of PVC, Hypalon, Neoprene or an Interlocked Aluminum or Steel Armor.
- g. Jacket: (Optional) A jacket of PVC, Hypalon or Neoprene may be employed under and/or over the metallic armor.

# Cyprus Wire & Cable Company Manufacturers of ROME Products

SPEC 7160

October 1, 1975

Supersedes Issue Dated March 1, 1975

## ROME-XLP POWER CABLE, 5000 VOLTS

Single Conductor, Shielded, 100% and 133% Insulation Levels

### APPLICATION:

A—Where NEC jurisdiction applies: as 5000-volt shielded power cable Type RHH, 75°C in wet locations; and 5000-volt shielded power cable Type RHH, 90°C in dry locations; when installed in accordance with Articles 310 and 710 of the National Electric Code.

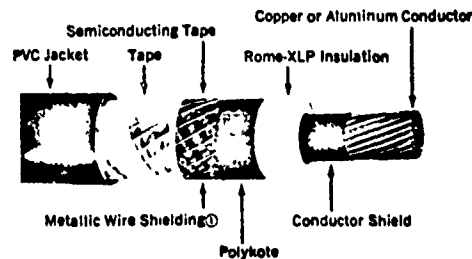
B—Otherwise, for general purpose applications in wet or dry locations, in circuits not exceeding 5000 volts, phase-to-phase, at conductor temperatures not exceeding 90°C for normal, 130°C for emergency overload, and 350°C for short circuit conditions. Suitable for installation in conduit, trays, troughs, ducts, aerial, and direct burial applications.

### STANDARDS:

A—Listed by Underwriters Laboratories as 5000-volt shielded Type RHW or RHH per Standard 44.

B—Conforms to IPCEA Publication No. S 66-524 for "Crosslinked-thermosetting-polyethylene-insulated Wire and Cable for the Transmission and Distribution of Electrical Energy."

CONSTRUCTION: Annealed copper or aluminum conductor, conductor shield, Rome-XLP thermosetting chemically crosslinked polyethylene insulation, PolyKote, semiconducting tape, #24 AWG metallic wire shielding, tape, black polyvinyl chloride jacket over-all, surface printed.



Size AWG or MCM	No. of Strands	Thickness in Mils		Nominal Diameter Over Ins Inches	Nominal Diameter Inches	S Indicates Stock Item	COPPER CONDUCTOR			ALUMINUM CONDUCTOR		
		Insulation	Jacket				Approx. Net Wt Lb / 1000 Ft.	Ampacity*		Approx. Net Wt Lb / 1000 Ft.	Ampacity*	
								Duct	D Burial		Duct	D Burial
2001-5000 VOLTS, SHIELDED, 100% and 133% INSULATION LEVELS (GROUNDED AND UNGROUNDED NEUTRAL)												
8	7	90	60	.34	.58	—	165	64	92	145	50	70
6	7	90	60	.38	.62	S	205	90	115	145	70	90
4	7	90	60	.43	.66	S	265	117	149	170	91	116
2	7	90	60	.49	.73	S	360	151	192	220	118	150
1	19	90	60	.54	.77	—	475	173	218	235	135	170
1/0	19	90	60	.57	.81	S	510	198	249	285	154	194
2/0	19	90	80	.62	.89	S	645	225	282	345	176	220
3/0	19	90	80	.67	.94	S	765	256	321	390	200	251
4/0	19	90	80	.73	1.00	S	915	292	365	465	229	285
250	37	90	80	.77	1.05	S	1050	320	399	515	251	313
350	37	90	80	.87	1.15	S	1395	386	477	630	304	376
500	37	90	80	1.01	1.28	S	1895	465	572	825	369	455
750	61	90	80	1.19	1.45	—	2745	565	693	1105	457	561
1000	61	90	80	1.34	1.63	—	3510	639	780	1395	527	644

\*Duct: Three cables per duct, 90°C Conductor Temperature, 20°C Ambient, 100% Load Factor, Rho = 90. Direct Burial: Three cables, close spacing, 90°C Conductor Temperature, 20°C Ambient, 100% Load Factor, Rho = 90. For other installation conditions, refer to the publication "AIEE-IPCEA Power Cable Ampacities," AIEE Pub. No. S-135-1.

①Bore copper metallic tape shield available on request.

Information on this sheet subject to change without notice.

**CYPRUS**

**Cyprus Wire & Cable Company  
Manufacturers of ROME Products**

7160 10-1-75

**Specification**

**ROME-XLP POWER CABLE, 5000 VOLTS**

**Single Conductor, Shielded, 100% and 133% Insulation Levels**

**SCOPE**—This specification describes single conductor Rome-XLP (thermosetting crosslinked polyethylene) insulated, shielded power cables for use in circuits not exceeding 5000 volts phase-to-phase at conductor temperatures of 90°C continuous normal operation, 130°C for emergency overload conditions and 250°C for short-circuit conditions. Cables are intended for general purpose applications in wet or dry locations, including conduit, duct, direct burial, and aerial installation.

**STANDARDS**—The following standards shall form a part of this specification — Underwriters Laboratories Standard 44 and IPCEA Pub. No. S-66-524 for "Crosslinked-thermosetting-polyethylene-insulated Wire and Cable for the Transmission and Distribution of Electrical Energy."

**CONDUCTORS**—Class B stranded annealed, uncoated copper or EC grade aluminum per Paragraphs 2.1 and 2.3 of IPCEA.

**CONDUCTOR SHIELDING**—The conductor shall be covered with a layer of semiconducting tape completely covering the conductor and firmly bonded to the cable insulation. The conductor shield shall meet the requirements of Paragraph 2.4 of IPCEA.

**INSULATION**—Directly over the conductor shielding shall be applied a homogeneous wall of Rome-XLP insulation. The average thickness of insulation shall be as specified in Table 3-1 of IPCEA. Minimum thickness at any point shall be not less than 90% of the specified thickness. Physical and electrical properties of the insulation shall be in accordance with Paragraph 3.7 of IPCEA.

**SHIELDING**—A thin uniform layer of Rome "PolyKote" (black conducting polymeric coating) shall be applied directly over the insulation. A semiconducting non-metallic tape is wrapped over the "PolyKote" to act as a conductive bedding between the "PolyKote" layer and the metallic shielding. A special marker tape applied over the semiconducting tape shall identify the tape and "Polykote" layers as conducting.

A serving of evenly spaced #24 AWG solid-tinned copper wires shall be applied concentrically over the semiconducting tape. The metallic wire shielding shall meet the requirements of Paragraph 4.1.1.3 of IPCEA.

**SEPARATOR TAPE**—A suitable separator tape shall be applied over the cable shielding system.

**JACKET**—A polyvinyl chloride jacket shall be applied overall. This jacket shall meet the requirements of Paragraph 4.3.1 of IPCEA. The average thickness of the jacket shall be as specified in Table 4-6 of IPCEA. The minimum thickness at any point shall be not less than 80% of that specified.

**IDENTIFICATION**—All cable shall have surface printed identification showing manufacturer's name, insulation type, size, UL symbol and 5000-volt shielded Type RHW or RHH.

**TESTS**—Cable shall be tested in accordance with UL Standard 44 and IPCEA S-66-524. Certified Test Reports may be furnished, if requested prior to production of cable.

**CYPRUS**

# Cyprus Wire & Cable Company Manufacturers of ROME Products

SPEC 7485

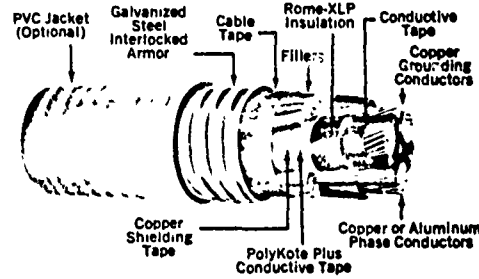
January 2, 1976

Supersedes Issue Dated March 1, 1975

## ROME INTERLOCKED ARMOR POWER CABLE, 5000 VOLTS

3 Conductor, Rome-XLP Insulated, Shielded, Galvanized Steel Armor

Type MV-90 Cable (Also suitable for use as Type MC cable)

<p><b>APPLICATION:</b>  A—Where NEC jurisdiction applies: as armored Type MV-90 cable for installation aerially or in metal rack, tray, trough or cable trays, for power circuits not exceeding 5000 volts in manufacturing and processing plants, substations and generating stations. When installed per the NEC, cables meet the requirements of OSHA.  B—Otherwise, for general purpose applications where the protection of interlocked armor is required.</p> <p><b>STANDARDS:</b> Listed by Underwriters Laboratories as Type MV-90 cable. Also suitable for use as Type MC cable. Cables also conform to IPCEA Pub. No. S-66-524 for "Crosslinked-Polyethylene-Insulated Wire and Cable."</p> <p><b>CONSTRUCTION:</b> Three conductors of stranded uncoated copper or Alloy 1350 (EC) aluminum, conductive tape, Rome-XLP (cross-linked polyethylene) insulation, PolyKote, conductive tape, uncoated copper shielding tape. Three conductors twisted together with one uncoated copper grounding conductor in each valley, suitable fillers, binder lace, galvanized steel interlocked armor. When required, a PVC jacket is applied overall.</p>											
Size AWG or MCM	No. of Strands	Insul. Thick. Mils	Nom Diam Over Armor Inches	Optional PVC Jkt Thick Mils	Nom Diam Over Opt. PVC Jkt Inches	COPPER PHASE CONDUCTORS			ALUMINUM PHASE CONDUCTORS		
						Copper Grounding Conductors AWG	Approx Net Wt * Lb /1000 Ft.	Ampacity*	Copper Grounding Conductors AWG	Approx Net Wt * Lb /1000 Ft.	Ampacity*
8	7	90	1.02	50	1.13	14	835	52	14	725	41
6	7	90	1.10	50	1.21	12	1015	69	12	840	53
4	7	90	1.21	50	1.31	10	1280	91	12	970	71
2	7	90	1.34	50	1.45	10	1630	125	10	1190	96
1	19	90	1.43	50	1.53	10	1870	140	10	1315	110
1/0	19	90	1.52	60	1.64	7	2280	165	10	1485	130
2/0	19	90	1.62	60	1.75	7	2640	190	10	1660	150
3/0	19	90	1.77	60	1.90	7	3205	220	7	2090	170
4/0	19	90	1.90	60	2.03	7	3755	255	7	2350	200
250	37	90	2.00	60	2.13	7	4220	280	7	2560	220
350	37	90	2.23	60	2.36	5	5640	350	7	3205	275
500	37	90	2.52	75	2.68	5	7440	425	5	4120	340
750	61	90	2.91	75	3.08	4	10245	525	5	5185	430

\*AMPACITY in accordance with Tables 310-42, 310-48 of the National Electrical Code, 90°C conductor temperature, 40°C ambient.

- Notes 1 Phase identification is provided by a longitudinal narrow colored tape between the conductive insulation shield and the copper shielding tape.  
2 Aluminum alloy or bronze interlocked armor available on request. Cables with aluminum alloy armor are UL listed.  
3 These cables also available with Rome-EPR insulation.  
4. Net weights based upon jacketed constructions.

Information on this sheet subject to change without notice.

**CYPRUS**

**Cyprus Wire & Cable Company**  
**Manufacturers of ROME Products**

7485 1-2-76

**Specification**

**Rome Interlocked Armor Power Cable, 5000 Volts**

**3 Conductor, Rome-XLP Insulated, Shielded, Galvanized Steel Armor**  
**Type MV-90 Cable (Also suitable for use as Type MC cable)**

**SCOPE** — This specification describes three conductor Rome-XLP (thermosetting crosslinked polyethylene) insulated, shielded, galvanized steel interlocked armor Type MV-90 power cable for use in circuits not exceeding 5000 volts phase to phase at conductor temperatures of 90°C for continuous normal operation, 130°C for emergency overload conditions and 250°C for short circuit conditions. Cables are intended for general purpose applications in aerial, open tray or rack installations, in wet or dry locations.

**STANDARDS** — The following standards shall form a part of this specification — UL Standard 1072 for Type MV-90 cable and IPCEA Pub. No. S-66-524 for "Crosslinked-thermosetting-polyethylene-insulated Wire and Cable."

**CONDUCTORS** — Class B stranded annealed uncoated copper or Alloy 1350 (EC) aluminum per Paragraphs 2.1 and 2.3 of IPCEA.

**CONDUCTOR SHIELD** — The conductor shall be covered with a layer of conductive tape completely covering the conductor firmly bonded to the cable insulation. The conductor shield shall meet the requirements of Paragraph 2.4 of IPCEA.

**INSULATION** — Directly over the conductor shield shall be applied a homogeneous wall of Rome-XLP insulation. The average thickness of insulation shall be as specified in Table 3-1 of IPCEA. Minimum thickness at any point shall be not less than 90% of the specified thickness. Physical and electrical properties of the insulation shall be in accordance with Paragraph 3.7 of IPCEA.

**SHIELDING** — A thin layer of Rome PolyKote (black conductive polymeric coating) shall be applied directly over the insulation. A conductive non-metallic tape is wrapped over the PolyKote to act as a conductive bedding between the PolyKote layer and the metallic shielding. A special marker tape applied over the conductive tape shall identify the tape and PolyKote layers as conducting.

An uncoated copper tape shall be helically applied over the conductive tape with a minimum lap of 10%. The copper tape shall meet the requirements of Paragraph 4.1.1.1 of IPCEA.

**PHASE IDENTIFICATION** — A colored tape shall be applied longitudinally under the copper shielding tape to provide phase identification.

**ASSEMBLY** — Three phase conductors shall be cabled together with a Class B stranded, uncoated copper grounding conductor in each valley and suitable fillers to make round. Length of lay shall not exceed 35 times the phase conductor diameter. Total circular mil area of the grounding conductors shall be not less than the copper conductor size listed in Table 250-95 of the National Electrical Code.

**CABLE TAPE** — A suitable cable tape shall be applied over the assembly to hold the core together and provide bedding for the armor.

**IDENTIFICATION** — A marker tape shall be applied longitudinally under the armor providing cable and manufacturer identification.

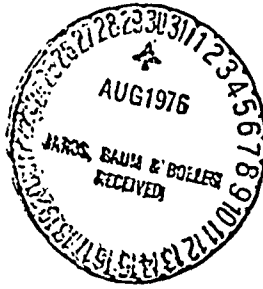
**ARMOR** — A galvanized steel interlocked armor shall be applied over the cable core. Armor shall be in accordance with UL Standard 1072 and Paragraph 4.4.7 of IPCEA.

**OPTIONAL COVERING** — When required, an extruded covering of PVC shall be applied over the armor. The average thickness shall be as specified in Table 4-24 of IPCEA. Minimum thickness at any point shall be not less than 80% of the specified thickness. Properties of the PVC covering shall be in accordance with Paragraph 4.4.16 of IPCEA.

**TESTS** — Cables shall be tested in accordance with UL requirements for Type MV-90 cable and IPCEA S-66-524. Certified Test Reports may be furnished, if requested prior to production of the cable.

**LABEL** — Cables shall bear the Underwriters Laboratories label for Type MV-90 cable.

**CYPRUS**



**ITT Royal Electric Division**

Pawtucket, Rhode Island 02862  
Tel. (401) 722-8600  
TELEX: 927733  
Cable Address: ITTWCD, Pawtucket, R. I.

August 25, 1976

Jaros, Baum & Bolles Consulting Engineers  
1052 West 6th Street  
Los Angeles, California 90017

Att: Mr. Paul Katzaroff

Subject: 400 Hertz Distribution System

Gentlemen:

I want to thank you for your inquiry of August 11. I am pleased to forward you our recommendation on the cable and cable construction we think should be used.

We believe you should use the 5 KV shielded cable, copper conductor, per IPCEA Standards S-68-516. I believe the cable should be three conductor or three single conductors triplexed. This will give you maximum personnel protection and minimum power losses.

Using ITT Royal Specially Compounded Ethylene Propylene Rubber Insulation there is no derating for either current or voltage on copper conductor sizes up to and including #2 AWG.

We suggest that when installing the cable in conduit or using Interlocked Armor that Aluminum metal be used. The use of non-magnetic metal will minimize the heating effect due to the increased frequency.

ITT Royal has been producing and marketing this type of cable for over seven years. With the special compounding of the insulation we have an extremely good record.

As for the termination of the 400 Hertz cable, the same type that are available for 60 Hertz are acceptable. You should use an aluminum body pothead, if potheads are used. Also any clamps that are to be used should be of non-magnetic material.

Jaros, Baum & Bolles  
Consulting Engineers

- 2 -

August 25, 1976

Again we want to thank you for your inquiry. We are pleased to forward you our recommendations and suggestions. If you have any additional questions, please do not hesitate to contact me.

Very truly yours,

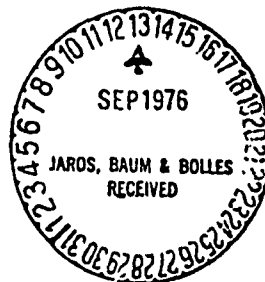
REA:cj  
cc: R. S. Ochsner  
J. R. Maher  
J. H. Grubbs(L.A.)

R. E. Anderson  
Regional Sales and  
Marketing Manager



501 Forbes Boulevard, Suite 201  
South San Francisco, California 94080  
415-873-8590

September 10, 1976



Jaros, Baum and Bolles  
1052 West 6th Street  
Los Angeles, California 90017

Attention: Mr. Paul Katzaroff

Subject: Feasibility Study - Centralized 60/400 HZ  
Generation and Distribution System

Gentlemen:

This is written in response to your letter dated August 11,  
1976 and the attached questionnaire:

1. (a) No derating is required for operating voltage. Although the heat loss in the dielectric varies with the square of the voltage the magnitude of such loss at 4160 volts is negligible for both 60 hZ and 400 hZ, and no significant acceleration in heat aging will occur.

However, it should be noted that the self and mutual reactance of the cables will vary directly with frequency, and cables installed in magnetic conduit or contained in galvanized steel interlocked armor will be significantly higher than for directly buried cables or those installed in a self-supporting aerial configuration.

The series impedance of the cables at 400 hZ will also be increased by increases in the resistance term due to skin and proximity effect. Like reactance, skin and proximity effects will be increased by containment in a magnetic conduit or armor.

- (b) Substantial current derating is required at 400 hZ due to the increase in effective AC resistance. You will find enclosed a copy of Okonite Engineering Bulletin 721.1, and your attention is called to

page 4 and 5 of the Bulletin. Table 1-6 shows derating factors for 600 volt cable due to increase in AC resistance at both 400 hZ and 800 hZ. As you will note this data does not take into account heat losses due to circulating currents in the short circuited shields of higher voltage cables, nor in the eddy current and magnetic effects of surrounding or adjacent metal. Table 1 - 7 on page 5 gives curves from which appropriate data is available for use with the equations shown at the bottom of page 4. But again these curves do not take into account the influence of surrounding or adjacent metals.

As the enclosed data indicates the derating factor will vary with conductor size, cable type and the installed configuration. Calculations are required for each size and category of cable to accurately determine the 400 hZ ampacity.

As indicated in (a) above, dielectric loss is negligible and does not contribute to ampacity derating at 400 hZ, 5 kV.

2. We recommend an ethylene propylene insulating compound for the various categories, since it has, in our view, the best balance of properties including resistance to heat aging, and resistance to corona discharge, and resistance to treeing. The trade name is Okoguard.
3. The Okonite Company introduced ethylene propylene compounds commercially in the last quarter of 1963, and has supplied hundreds of thousands of feet since then in the various categories enumerated in 2.
4. No special precautions are required in the cable terminations themselves. However, care must be exercised in locating terminations to avoid local heating of the cable due to proximity of magnetic structures, where ampacities have been based on the absence of such structures or enclosures.

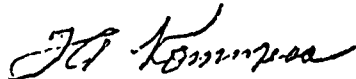
The rather standard specification provision that splices and terminations shall be made in accordance with manufacturers prior written approval appears to be both simple and effective.

Mr. Paul Katzaroff  
September 10, 1976  
Page 3

The opportunity to respond to your questionnaire is very much appreciated. If you have additional questions, please let me hear from you at your convenience.

Very truly yours,

THE OKONITE COMPANY



T. A. Kommers  
Regional Electrical Engineer

TAK:pa

(3) Motor Generators

<u>Mfr. Name</u>	<u>Response</u>	<u>Description</u>
Bogue Electric Machinery Mfg. Co.	No Yes	Irrelevant - submitted Bull. 200 SYN 51A and AIEE Conference Paper No. 61-607 which are very general. Promised follow up, but, did not do so in spite several telephone contacts.
GE	Yes	Letter dated October 5, 1976
Kato	No	
Teledyne Inet	Yes	Letter dated November 11, 1976
		Letter dated November 22, 1976 - covers 60/400 Hz motor generators at 480V and 4160V. Also covers an unsolicited proposal for a completely solid state 4160V frequency conversion system.
Westinghouse	Yes	Letter dated September 12, 1976 - Irrelevant - concerns 75 KVA 60/400 Hz motor generators for computer applications.



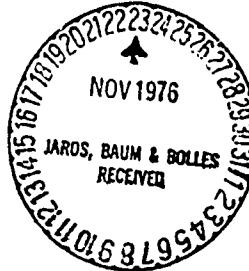
711 WEST KNOX STREET

GARDENA, CALIFORNIA 90245

(213) 327-0913 TELEX 67-7228

22 November 1976

Jaros, Baum and Bolles  
1052 West 6th Street  
Room 636  
Los Angeles, California 90017



Ref. 26326-6

Attention: Mr. Paul Katzaroff

Gentlemen:

Subject: 400 Hz High Voltage Distribution

Thank you for the opportunity to work with you on your requirement for 400 Hz High Voltage Distribution System. We have reviewed your requirement and offer the following for your preliminary planning purposes.

Plan A. Vertical Brushless Synchronous Motor-Generator Sets for indoor use capable of paralleling with like units under all load conditions within unit rating.

Input: 480 volts, 3-phase, 60 Hz  
Output: 575 volts to step up transformer  
4160 volts, 3-phase, 400 Hz,  
312 KVA, 250 KW

The Motor-Generator Set will be complete with all instruments, controls, starter and output breaker. Includes motorized stator shifting assembly for paralleling and deparalleling with all synchronizing lights and load sharing circuitry.

Planning Price, Qty. 4 (1 redundant) \$ 45,000. each

Plan B. Vertical Brushless Synchronous Motor-Generator Set rated 312 KVA. Same as Plan "A" except the input will be 4160 volts, 3-phase, 60 Hz. Both the motor and generator will be designed for direct 4160 volts, 60 Hz, 3-phase input and 400 Hz, 3-phase output without use of step up transformer. Includes high voltage input and output switchgear.

Planning Price, Qty. 4 (1 redundant) \$ 85,000. each

Jaros, Baum and Bolles  
Mr. Paul Katzaroff

22 November 1976  
Page two

Each of the above motor-generator systems may be expanded by the addition of like units. Six copies each of Bulletin 2100-A and 473 are enclosed. Also efficiency curves for Plans "A" and "B" along with photographs of a typical 4-unit 400 Hz parallelable system.

Plan C. Completely Solid-State Power System operating directly from a 4160 VAC, 3-phase, 60 Hz power source and delivering 4160 volts, 3-phase, 400 Hz. The system consists of four identical units each rated 312 KVA, 250 KW operating in parallel to furnish 936 KVA, 750 KW, 400 Hz power with one unit redundant. The system will be expandable with the addition of identical units.

For your planning purposes, pricing on the solid-state system is as follows:

1. Four Power Converters 60/400 Hz, 312 KVA, 250 KW.

Price: \$ 64,000. each

2. Four Switchgear Assemblies 4160 VAC, 60 Hz input and 4160 VAC, 400 Hz output.

Price: \$ 6,000. each

Enclosed are six copies of a Technical Proposal dated 19 November that describes the solid-state system offered above.

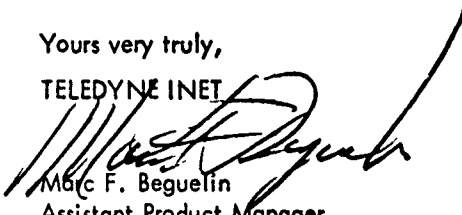
In addition one control console for control and metering of the entire system for either rotary or solid-state could be furnished at a unit price of \$10,000.

On any initial orders the nonrecurring costs for the 4160/4160 rotary and solid-state system approximately \$50,000 would be amortized.

The above pricing is for your planning purposes only. If you have any questions or require additional data, please do not hesitate to contact us.

Yours very truly,

TELEDYNE INET

  
Marc F. Beguelin

Assistant Product Manager  
Power Conversion Equipment

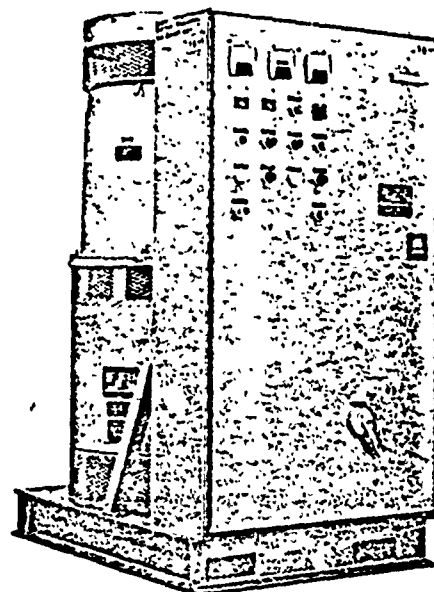
MFB/crk  
Enclosures

cc: H. Bauer, R. Lee, J. Vallely

# TELEDYNE INET Series 2100

## Motor Generator Frequency Converters

Teledyne Inet's vertical, brushless, single-exciter Motor Generator Frequency Converters provide precise 400 Hz power for computer support and related data communications equipment. They are specifically designed to interface with IBM 370/165-168, 360/85-195 and similar computer models. Teledyne Inet's Frequency Converters offer the lowest operating cost, highest efficiency and greatest reliability available in 400 Hz power conversion units (MTBF 50,000 hours). The units are easily paralleled for redundancy and increased load requirements. Ratings up to 300 KVA available with automatic paralleling. Unit options are available for your specific application.



VERTICAL SINGLE SHAFT  
TWO BEARING MOTOR GENERATOR

### ELECTRICAL SPECIFICATIONS

#### Input

Voltage	440, 460, 480 VAC (208 or 240 optional), 3-phase, 3 or 4 wire
Frequency	60 Hz
Power Factor	0.9 to 1.0 from ½ load to full load
Starting Current	Limited to 400% of rated full load current

Short Circuit Voltage Transient	300% of rated current $\pm 5\%$ max. from preset value with sudden loss or application of ½ rated load at 0.9 p.f.
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Voltage Recovery	Within 0.2 seconds upon sudden loss or application of rated load
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#### Output

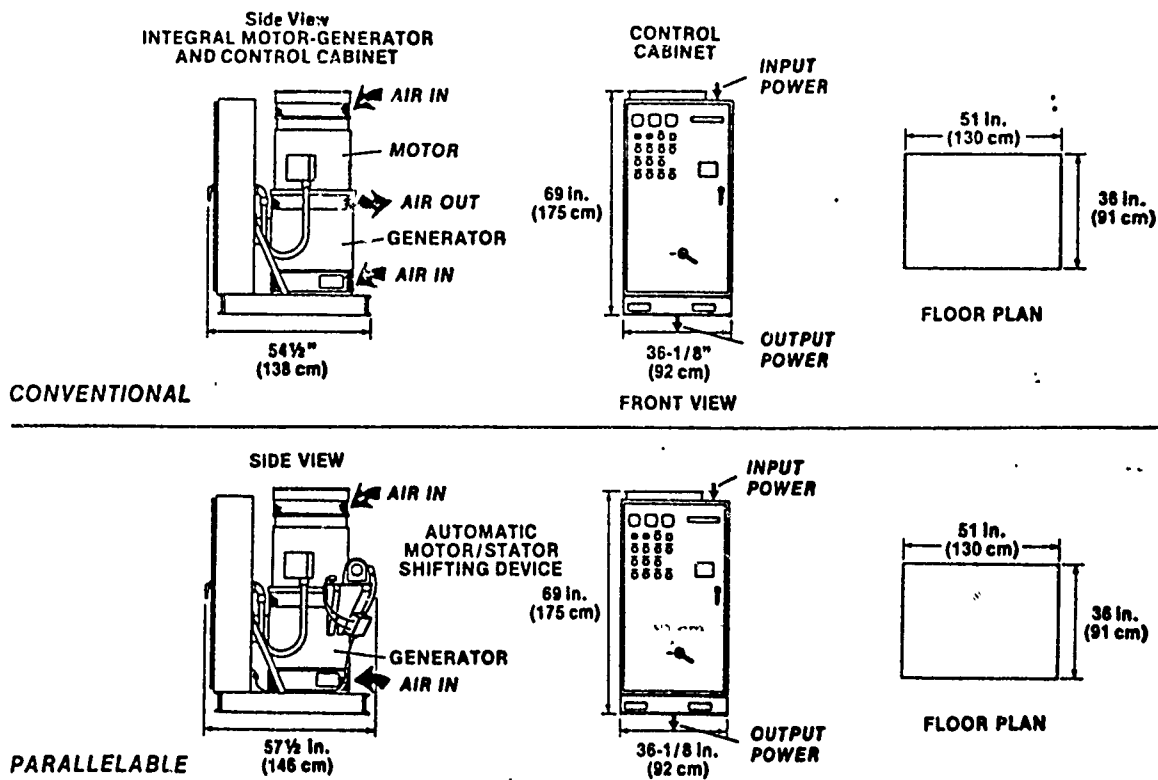
Rating	75 KVA, 67.5 KW
Voltage	120/208, 3-phase, 3 or 4 wire
Efficiency	80%
Frequency	400 Hz
Power Factor	0.9
Voltage Adjustment	$\pm 10\%$ minimum
Voltage Regulation	$\pm 1\%$ no load to full load
Overload Capacity	110% of rated load, continuous; 120% of rated load for ½ hour

Phase Voltage Balance	½ % max. line-to-line and line-to-neutral with balanced rated load
-----------------------	--

Harmonic Content	1.5% RMS max. line-to-line, line-to-neutral
------------------	---

Frequency Regulation	$\pm 0\%$ with $\pm 0\%$ input frequency variation
----------------------	--

Voltage and Frequency Modulation	0.25% max.
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### SICAL SPECIFICATIONS

Dimensions	<i>Conventional</i>
	36-1/8"W x 69"H x 54-1/2"D (92 cm x 175 cm x 138 cm)
	<i>Parallelable</i>
	36-1/8"W x 69"H x 57-1/2"D (92 cm x 175 cm x 146 cm)
Weight	<i>Conventional</i>
	3,850 lbs. (1,800 kg)
	<i>Parallelable</i>
	4,000 lbs. (1,878 kg)
Ventilation	Self-ventilating
Cable Entry	Top and bottom
Acoustic Noise	86 db at 12 ft. (3.65 m)

### STANDARD FEATURES

- Output voltmeter and ammeter
- System fault protection and alarms
- PDCU wiring 50 VDC
- Elapsed time meter
- Reduced current starting
- Automatic NL/FL paralleling by motor/stator shifting

*Note: Induction motor-driven MG with 500 ms ride-through available  
(See Bulletin 1001)*

### ENVIRONMENTAL SPECIFICATIONS

Operating Temperature Range	Recommended	20°C to 30°C
	Maximum	-20°C to 52°C
Nonoperating temperature Range		0°C to 70°C
Relative Humidity		0 to 95 percent
Altitude		0 to 5000 ft. (0 to 1524 m)

### OPTIONS AND SERVICES

- Utility start, UPS run
- Central system buss isolation available
- Noise suppression kits
- UL approved
- Turnkey contracts
- Leasing arrangements
- Maintenance agreements
- Installation supervision
- Site testing

*(Refer to individual Bulletins for details on above  
Options and Services)*

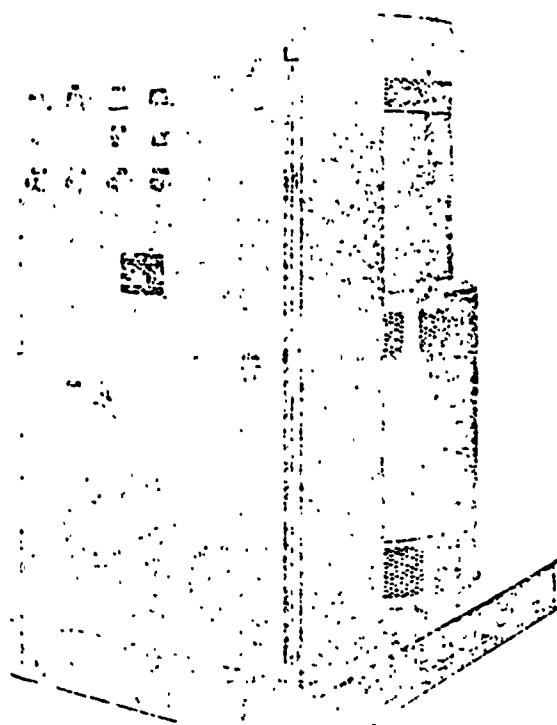
*All specifications subject to verification for each order.*

**TELEDYNE INET**

711 West Knox Street • Gardena, California 90248 • Telephone: (213) 327-0913 • Telex: 67-7228

BEST AVAILABLE COPY

## TELEDYNE INET 2100 and 4300 SERIES 400 Hz VERTICAL MOTOR GENERATORS



### PRECISE GROUND POWER EQUIPMENT AND COMPLETE SYSTEMS FOR:

- all jet aircraft
- hangar and flight line maintenance facilities
- aircraft manufacturers
- computer power
- aerospace industries and laboratories
- all branches of military services
- other government agencies

— HIGHEST QUALITY POWER — HIGHEST  
RELIABILITY — LOWEST LIFE CYCLE COST

### VERTICAL SYNCHRONOUS BRUSHLESS SINGLE EXCITE = SINGLE SHAFT-2 BEARING MOTOR GENERATORS

- No slip rings or brushes — eliminates maintenance from brush and slip ring wear — reduces radio frequency interference (RFI) noise — safe for operation in hazardous areas.
- Vertical design eliminates shaft deflection from gravity inherent in horizontal machines, reducing vibration and noise, increasing bearing life.
- Eliminating shaft deflection maintains a uniform air gap — modulation of output voltage is nearly eliminated.
- Magnetic forces of the rotor produce a lifting action which reduces load on the lower thrust bearing which runs in an oil reservoir — top bearing is nearly without load — greatly increasing bearing life.
- Overload capability: 10% continuously, 25% for 30 minutes.
- Requires less floor space than horizontal configuration.
- Quiet efficient blower assures ample cooling under high ambient temperatures.
- High reliability — individual units have logged 50,000-100,000 hours of continuous operation.
- Minimum maintenance — inspection recommended twice each year.
- Vertical design permits two or more sets to operate in parallel by servo drive rotation of motor with respect to the generator on a bearing surface to obtain phase shifting. System power capacity can be increased as demand increases. Higher power distribution reliability can be obtained with redundancy.
- Solid non-deforming cast frames.
- Inherent low radio frequency interference (RFI) noise.
- Voltage transient limits of less than 20% with application or removal of full load are available.

### SOLID STATE VOLTAGE REGULATOR/PROTECTIVE MODULE

- Regulator module simultaneously controls both Motor Field and Generator Field keeping power factor on input AC Power near unity — this minimizes input current requirements with all load variations.
- Printed circuit modules for OV/UV, UF and Regulation are field replaceable at minimal expense.
- Maximum harmonic content of 0.5% total RMS line to line or line to neutral is available on some sizes.
- Insensitive to temperature variations over the range of 0°F to 135°F.
- Adjusts over  $\pm 10\%$  range of nominal voltage.
- Fast regulation — 0.2 seconds recovery switching no load to full load — 0.1 seconds available
- All silicon military quality semi conductors.

### CUSTOMERS INCLUDE:

AIRCRAFT MANUFACTURERS — Boeing; General Dynamics; Grumman; Lockheed; McDonnell-Douglas; North American Rockwell; Northrup.

AIRLINES — Air Canada; Air India; Air Vietnam; Alaska; Braniff; China, Continental, Eastern, El Al, Ethiopian, Finnair; Frontier; Icelandic; Northwest Orient, Olympic, Pacific Southwest; Pakistan International; Saudi Arabian, Texas International, Trans World Airlines, Qantas, United Air Lines; Wien Consolidated; World Airways.

AEROSPACE INDUSTRIES — Aerojet General, Burroughs; General Electric, Hughes Aircraft, Ling Temco-Vought, Litton Systems; Philco-Ford, Raytheon, RCA, Sylvania, Texas Instrument; TRW; Westinghouse Electric.

U.S. GOVERNMENT — Atomic Energy Commission; Federal Aviation Agency, General Services Administration, Jet Propulsion Laboratories, National Aeronautics and Space Administration; US Air Force, US Army, US Coast Guard, US Marine Corps, US Navy.

**TELEDYNE INET**

... PIONEERS IN PRECISE POWER

## STANDARD PERFORMANCE SPECIFICATIONS

### RATINGS

1 Phase — 40 to 500 KW  
50 to 625 KVA

### INPUT VOLTAGE

3 Phase 230, 460, 230/460 volts,  
60 Hz  
3 Phase 220, 380, 220/380 volts,  
50 Hz  
Special — Per customer needs

### OPERATING SPEED

1200 RPM with 60 Hz input  
1500 RPM with 50 Hz input

### OUTPUT VOLTAGE

3 Phase — 115/200 volts  
Single Phase — 120 volts  
Special — Per customer needs

### VOLTAGE REGULATION

$\pm 1\%$  of rated voltage, no load  
to full load;  $\pm 1\%$  available.

### VOLTAGE RECOVERY TIME

0.2 seconds to full recovery after  
switching 100% load — 0.1  
seconds recovery available.

### VOLTAGE TRANSIENT LIMITS

Less than 20% with application  
or removal of full load — down  
to 5% available.

### VOLTAGE MODULATION

Less than 1% at balanced load.

### PHASE BALANCE (Unbalanced)

4% maximum voltage deviation  
from the average with 1/3 rated  
current on one phase and no  
load on other two — to 2%  
deviation available.

### HARMONIC CONTENT

3 Phase units — 1% total RMS  
— to 0.5% (consult factory)  
(Line to line, line to neutral)  
Single Phase unit — 2% total RMS

### FREQUENCY REGULATION

400 Hz  $\pm 0$  Hz with  $\pm 0$  Hz input  
frequency variation

### FREQUENCY MODULATION

Less than 1% of 400 Hz

## POSSIBLE PROBLEMS OF 400 Hz POWER DISTRIBUTION INCLUDE:

1. High voltage drops limit the length of distribution lines.
2. Line losses require correction to deliver acceptable power.
3. Serving multiple load points from a single generator demands special controls.
4. Unbalanced phase loading requires compensation.

### TELEDYNE INET HAS THE ANSWERS

Through development of integrated 400 Hz Power Systems that GUARANTEE precise quality power from a single generator source for up to 6 load positions and up to 1200 feet from source using standard distribution lines. This is possible only with accessories exclusively designed and built by Teledyne Inet.

### TELEDYNE INET OFFERS

1. Wide choice of options — already engineered conservative designs — optimized by computer.
2. Total system design engineering.
3. All major components built "in house" insuring total system responsibility.
4. Field installation or supervision support as required.
5. Spares/service consultation — 24 hours/day.

### TELEDYNE INET ACCESSORIES FOR 400 Hz SYSTEMS

#### LINE DROP COMPENSATOR

Automatically compensates for reactive voltage drops up to 20% in lines connecting the generator and load. Voltage at the loadpoint is regulated to  $\pm 3\%$  for all conditions within the motor generator rating.

- Provides acceptable voltage regulation at aircraft skin or load point when unbalanced phase loading occurs.
- Speed of response of system is maintained at aircraft skin or load point identical to that at generator.
- Convection cooled — small — lightweight.
- Solid-state design — MTBF over 100,000 hours — efficiency over 99%.
- Exclusive from Teledyne Inet.

#### LINE VOLTAGE REGULATOR

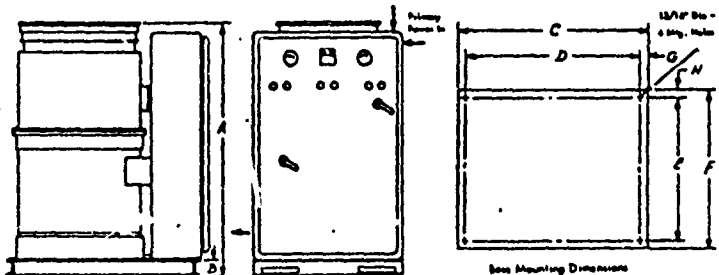
- Differs from line drop compensator in that it provides actual regulation at the load independent of input voltage.
- will reduce or boost voltage up to 10% of applied input per phase.
- Convection cooled — small — lightweight.
- Solid-state design — MTBF over 5,000 hours — efficiency over 98%.
- Exclusive from Teledyne Inet.

#### STEP DOWN TRANSFORMER

- Installation cost of distribution lines can be reduced by generating 400 Hz power at up to 600 volts and employing a step down transformer to 120/208 volts at individual load points.

#### ELECTRO-MAGNETIC INTERFERENCE FILTER

- MIL-STD 461A for Class III B equipment can be complied with through incorporation of Teledyne Inet RFI filters in motor generators, controls and accessories.



Base Mounting Dimensions

RATING	A	B	C	D	E	F	G	H
40-125 KW	8 1/2	6	5 1/2	42	34 1/2	36 1/2	4	1/2
130-250 KW	8 1/2	6	5 1/2	48	38 1/2	40 1/2	4	1/2
300-500 KW	7 1/2	5	4 1/2	—	—	—	—	—

Model No	KW Rating	KVA @ 8PF	Motor HP	60 Hz Full Load Amps @ 460V	Unit Weight
21040	40	50	65	70	3650
21050	50	62.5	85	90	3770
21060	60	75	100	104	3950
21075	75	93.75	120	118	4250
21100	100	125	150	154	4400
21125	125	156	185	188	4750
21150	150	187.5	225	226	5800
21175	175	219	260	260	6200
21200	200	250	300	300	6700
21250	250	312	375	374	7100
21400	400	500	600	598	9120
21500	500	625	750	746	9920

For complete specifications including optional features, request:  
Bulletin 2100 for 60 Hz input Bulletin 4300 for 50 Hz input.

**TELEDYNE INET**

711 WEST KNOX STREET GARDENA, CALIFORNIA 90248 TELEPHONE (213) 327-0913 TELEX NO. 67-7228

STANDARD SPECIFICATIONS  
BRUSHLESS 60/400 CPS SYNCHRONOUS MOTOR-GENERATOR SETS

1.0 SCOPE

This specification describes performance, configuration, construction and reliability parameters for synchronous motor-generators, with controls and accessories, for converting 3-phase electrical power to precisely regulated 400 cps power.

The power conversion system is completely self-contained requiring only connections to the input power source and the load circuit to perform all functions described herein. If the controls are to be installed remote from the motor-generator, interconnections between the locations will also be required.

The type of enclosure for the motor-generator and controls will be as selected from the Construction and Enclosure listing at the end of this specification.

2.0 OUTPUT RATINGS

Three-Phase Models	5 to 500 KW, 6.25 to 625 KVA 0.8 power factor.
--------------------	---

Single-Phase Models	3 to 125 KW, 3.75 to 156 KVA 0.8 power factor.
---------------------	---

Refer to the section titled "Model Numbers" at the end of this specification for individual ratings and models.

3.0 RELIABILITY

A degree of reliability is specified which assures that operating and maintenance costs will be held to a minimum. However, this is accomplished without imposing unusual design requirements and unreasonable initial cost.

3.1 STATISTICAL RELIABILITY The motor-generator and voltage regulator have a Mean Time Before Failure of at least 15,000 hours under continuous rated load operation.

3.2 **MAINTENANCE** No servicing or maintenance will be required at less than 9000-hour intervals. However, in installations where moisture, vapors, dust and other particles may impinge upon windings and other electrical components, periodic cleaning such as with clean compressed air may be required depending upon the specific environmental conditions.

3.3 **FAIL-SAFE DESIGN** The system is self-protecting from malfunctions, and provides isolation of component failures so as to minimize the possibility of consequent damage to other sections of the system and the load.

#### 4.0 **CONSTRUCTION**

The system consists of a motor, generator, exciter and voltage regulator; standard controls, protective devices, and instrumentation; and optional accessories as may be specified.

4.1 **ROTATING EQUIPMENT** The motor, generator and exciter are combined on a common shaft, two-bearing, self-ventilating, 1200 RPM, and the completed shaft assembly is statically and dynamically balanced.

The windings are impervious to oil, solvents, moisture, mild acids and alkalies, and receive a minimum of two impregnation and baking cycles.

4.1.1 **Motor Generator** The motor and generator are synchronous, brushless, rotating field type, with Class F insulation, and in conformance with NEMA Standard MG-1.

4.1.2 **Exciter** The exciter is a brushless rotating AC type, with the output rectified by a shaft-mounted three-phase silicon rectifier assembly to provide excitation for both the motor and generator. Separate exciters for the motor and generator may be required for special applications and ratings above 200 KW.

The exciter-voltage regulator effectively isolates the generator output from transients in the input AC supply.

4.2 **VOLTAGE REGULATOR** The voltage regulator is completely solid state with no electronic tubes or vibrating contacts, and is fully stabilized against long-term drift and ambient temperature variations.

4.3 CONTROL CABINET Unless specified otherwise by the user, all controls, indicating lights, protective devices and instruments are mounted in the control cabinet.

4.4 WIRING All wiring has ample service loops and is protected from abrasion. Wiring and wiring harnesses are secured at least every six inches. All terminals are identified in accordance with the wiring diagram.

## 5.0 ELECTRICAL CHARACTERISTICS

### 5.1 INPUT POWER

<u>Voltage Input</u>	460 volts $\pm$ 10%, 3-phase, 60 cps (For other voltage ratings refer to the section at the end of this specification titled, "Optional Features Available").
----------------------	--

#### Motor Power Factor

Single Exciter Models	Approximately 1.0 at rated load and voltage, and between unity and 0.9 from one-half load to full load.
-----------------------	---

Dual Exciter Models (Special applications and ratings above 200 KW)	Motor power factor is adjustable for any load by the "Motor Field Adjustment" provided on the control panel. This controls the field of the exciter which provides excitation to the motor.
--	---

5.2 EFFICIENCY When operated at rated frequency and voltage, the minimum unit efficiencies are:

7.5 - 15 KW	65%
20 - 30	70
40 - 75	75
100 - 150	80
Above 150	85

### 5.3 OUTPUT RATINGS

Three-Phase Models	5 to 500 KW, 6.25 to 625 KVA 0.8 power factor.
--------------------	---

Single-Phase Models      3 to 125 KW, 3.75 to 156 KVA  
0.8 power factor.

#### 5.4 VOLTAGE OUTPUT

##### Three-Phase Models

To 250 KW      115/200 or 120/208 volts, 4-wire, wye

Above 250 KW      254/440 or 277/480 volts, 4-wire, wye

Single-Phase Models      115 or 120 volts, 2-wire

For other voltage ratings refer to the section at the end of this specification titled, "Optional Features Available".

5.5 VOLTAGE BUILD-UP Initial voltage build-up is completely automatic.

5.6 VOLTAGE ADJUSTMENT  $\pm 10\%$ , minimum adjustment range.

5.7 VOLTAGE REGULATION  $\pm 1/2\%$  from no load to full load.

5.8 VOLTAGE STABILITY The voltage regulator stabilizes the output voltage within one minute after start-up, and compensates for long-term drift and ambient temperature variations.

5.9 VOLTAGE TRANSIENT LIMITS Upon sudden application or removal of full rated load at rated power factor, the output voltage will not deviate by more than  $\pm 25\%$  from the preset value.

5.10 VOLTAGE RECOVERY TIME Following sudden application or removal of full rated load the output voltage will recover to the regulation band within 0.2 seconds.

5.11 PHASE VOLTAGE BALANCE (Three-phase Models) The individual line-to-neutral voltages remain balanced within 1% under all balanced load conditions.

With one-third rated load on any phase and no load on the other two phases, or any similar condition of one-third load unbalance, the maximum deviation of any phase voltage from the average of the three phase voltages will not exceed 4%, in accordance with the requirements of MIL-STD-704.

5.12 OVERLOAD CAPABILITY 110% of rated load, continuous; 120% of rated load for one-half hour.

5.13 SHORT-CIRCUIT CAPABILITY The system is capable of delivering 300% of rated current into a sustained three-phase short circuit, until the system protective device is actuated.

5.14 HARMONIC CONTENT

Three-phase Models	1.5% RMS, maximum, line-to-line and line-to-neutral.
--------------------	--

Single-phase Models	3% RMS, maximum.
---------------------	------------------

5.15 MODULATION Voltage and frequency modulation do not exceed 0.25%.

5.16 FREQUENCY REGULATION  $\pm 0\%$  with  $\pm 0\%$  input frequency variation.

5.17 ELECTROMAGNETIC INTERFERENCE SUPPRESSION Conducted and radiated electromagnetic interference are suppressed so as not to affect the normal operation of communications and other types of electronic equipment.

If conformance is required to MIL-I-6181, MIL-I-16910, MIL-I-26600, MIL-STD-826 or individual user requirements, specify in accordance with the 'Optional Performance Available' section at the end of this specification. RFI tests will be performed, and additional filtering incorporated, if necessary, to meet the applicable specification.

6.0 CONTROL, PROTECTIVE DEVICES AND INSTRUMENTS

6.1 INPUT CIRCUIT

Motor Starter, magnetic, in accordance with NEMA Standard 1C-1, with overload and undervoltage protection.

Note: Ratings to 50 KW	Across-the-line starter, unless specified otherwise by the user. Refer to the 'Optional Features Available' section.
------------------------	--

Above 50 KW	Reduced current starting system limiting the motor starting current to 400% of rated full load current.
-------------	---

'Start-Stop' pushbutton and 'Motor-On' indicating light, low-voltage transformer type.

Control circuit transformer, fused, with 120 volt single-phase secondary for operating the control and indicating devices.

## 6.2 OUTPUT CIRCUIT

Circuit breaker, industrial type, with thermal overload and short-circuit protection.

'Load-On' indicating light, low-voltage transformer type.

Output voltage adjustment, screwdriver type with locknut, providing  $\pm 10\%$  minimum adjustment range.

## 6.3 INSTRUMENTS

Output Voltmeter and Ammeter, 3-1/2 inch, 2% or better accuracy, calibrated for the output frequency.

Three-phase models include a selector switch for monitoring individual line-to-neutral voltages and phase currents.

6.4 Additional control and protective devices, and instruments are available as listed in the 'Optional Features Available' section at the end of this specification.

## 7.0 INSTALLATION, OPERATION AND MAINTENANCE INSTRUCTIONS

A manual containing the following information is provided with each system:

- System description and specifications
- Installation and pre-start procedures
- Starting and operation instructions
- Theory of operation
- Maintenance instructions
- Replacement-parts list
- Schematic and point-to-point wiring diagrams

MODEL NUMBERS - BRUSHLESS 60/400 CPS SYNCHRONOUS MOTOR GENERATORS

<u>KW</u>	<u>KVA</u>	<u>BASIC MODEL NUMBERS</u>	
		<u>Three-Phase Output</u>	<u>Single-Phase Output</u>
3	3.75	-	22003
5	6.25	21005	22005
7.5	9.38	21007	22007
10	12.5	21010	22010
15	18.75	21015	22015
20	25	21020	22020
25	31.25	21025	22025
30	37.5	21030	22030
40	50	21040	22040
50	62.5	21050	22050
60	75	21060	22060
75	93.75	21075	22075
100	125	21100	22100
125	156	21125	22125
150	188	21150	-
175	219	21175	-
200	250	21200	-
250	312.5	21250	-
300	375	21300	-
350	437.5	21350	-
400	500	21400	-
450	562.5	21450	-
500	625	21500	-

SPECIFYING BY MODEL NUMBER

A complete model number consists of the BASIC MODEL NUMBER, above, plus:

Prefix code letter specifying the type of CONSTRUCTION AND ENCLOSURE; and

Suffix code letters and numbers designating OPTIONAL FEATURES and OPTIONAL PERFORMANCE DESIRED.

Example: Model T-21075 specified a standard model without options.

Model T-21075-ACFJK-6 specifies a standard model plus options as listed on the following pages.

OPTIONAL FEATURES AVAILABLE

Add applicable code letters as suffix to Basic Model Number

INPUT VOLTAGE

- B 230 volts, 3-phase.
- C 230/460 volts, 3-phase.  
Note: If reduced motor starting current, Code A, is also desired,  
the application must be reviewed by the factory.
- T 4160 volts, 3-phase.
- U Special, per user requirements.

OUTPUT VOLTAGE

- N 115 or 120 volts, 3-phase delta.
- O Reconnectable 3-phase wye or delta.
- P Reconnectable 3-phase full range, 120/208 & 240/416 volts.
- W Special, per user requirements.

METERS

- J Output frequency meter, reed type.
- K Running time meter, 10,000 hour scale.
- Y Special, per user requirements.

ADDITIONAL CONTROL & PROTECTIVE DEVICES

- A Reduced motor starting current:  
Models up to 30 KW - 300% of full load rated input current  
Models above 30 KW - 400% of full load rated input current  
  
NOTE: (1) This feature is standard and included on models above 50 KW  
(2) If dual input voltage, Option C above, is desired together with  
reduced motor starting current, the application must be reviewed  
by the factory.
- D Out-of-step synchronous motor protection. If the motor falls out of synchronism,  
the input circuit to the motor is de-energized.
- F Output overvoltage protection, with fault indicating light and manual reset,  
opens the shunt trip in the output circuit breaker.
- H Output undervoltage protection, with fault indicating light and manual reset,  
opens the shunt trip in the output circuit breaker.
- Q Input circuit breaker.
- R Output magnetic contractor, with 'On-Off' pushbuttons and indicating lights.
- S Remote sensing of the output voltage, with fail-safe protection. In the event  
of an open circuit in the remote sensing leads, voltage regulator sensing  
automatically reverts to the generator output terminals.
- V Phase sequence protection prevents unit starting with reversed phase sequence.
- Z Special input and/or output features, per user requirements.

OPTIONAL PERFORMANCE AVAILABLE

Add applicable code numbers as suffix to Basic Model Number

- 1 Voltage regulation better than standard, reference Para. 5.7 - To be specified by user
- 2 Voltage recovery better than standard, reference Para. 5.10 - "
- 3 Voltage transient better than standard, reference Para. 5.9 - "
- 4 Phase balance better than standard, reference Para. 5.11 - "
- 5 Harmonic content better than standard, reference Para. 5.14 - "
- 6 Electromagnetic interference suppression in accordance with required MIL specifications or individual user requirements, reference Paragraph 5.17.
- 9 Other special performance requirements - To be specified by user.

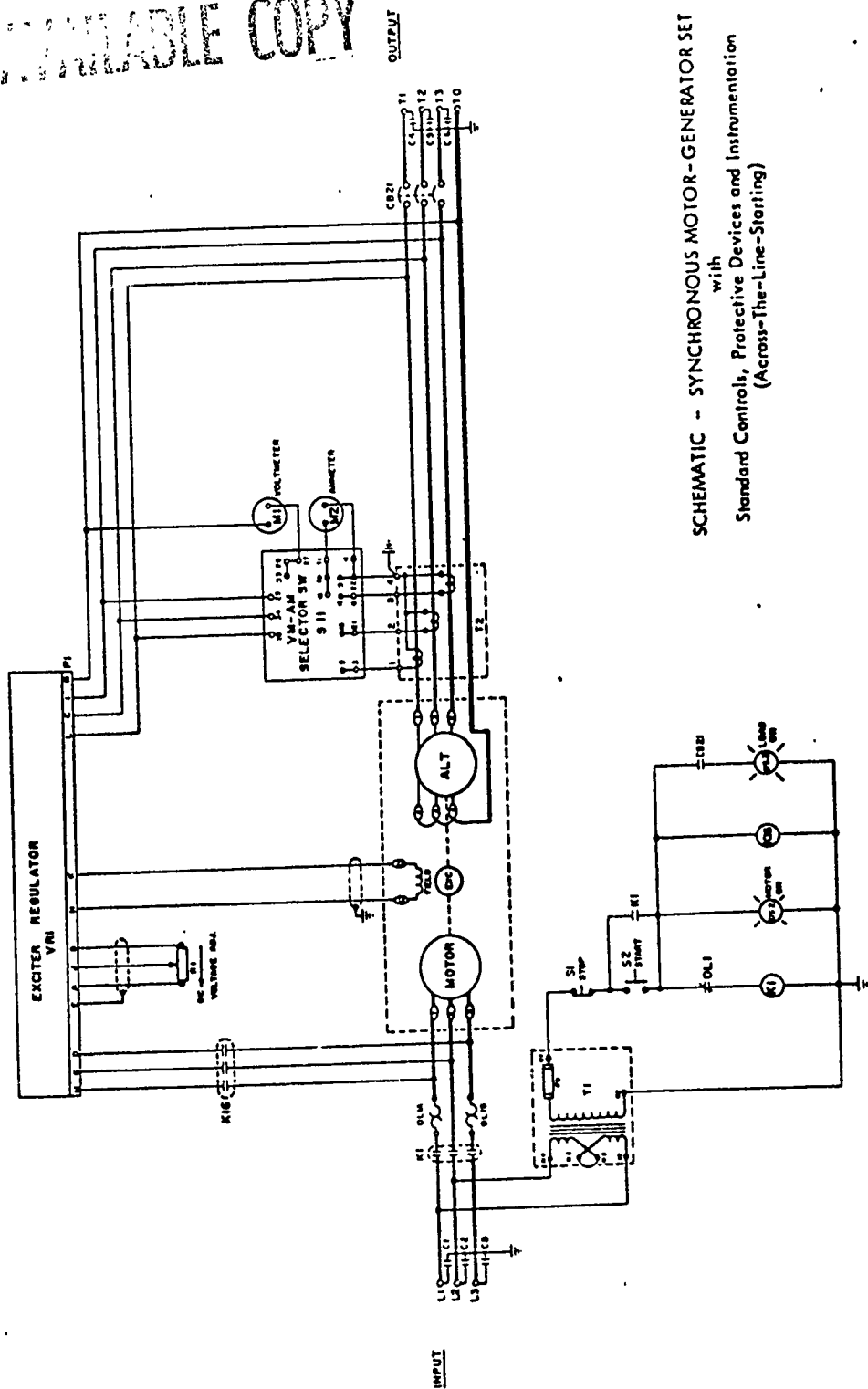
CONSTRUCTION AND ENCLOSURE

List applicable code letter as prefix to Basic Model Number

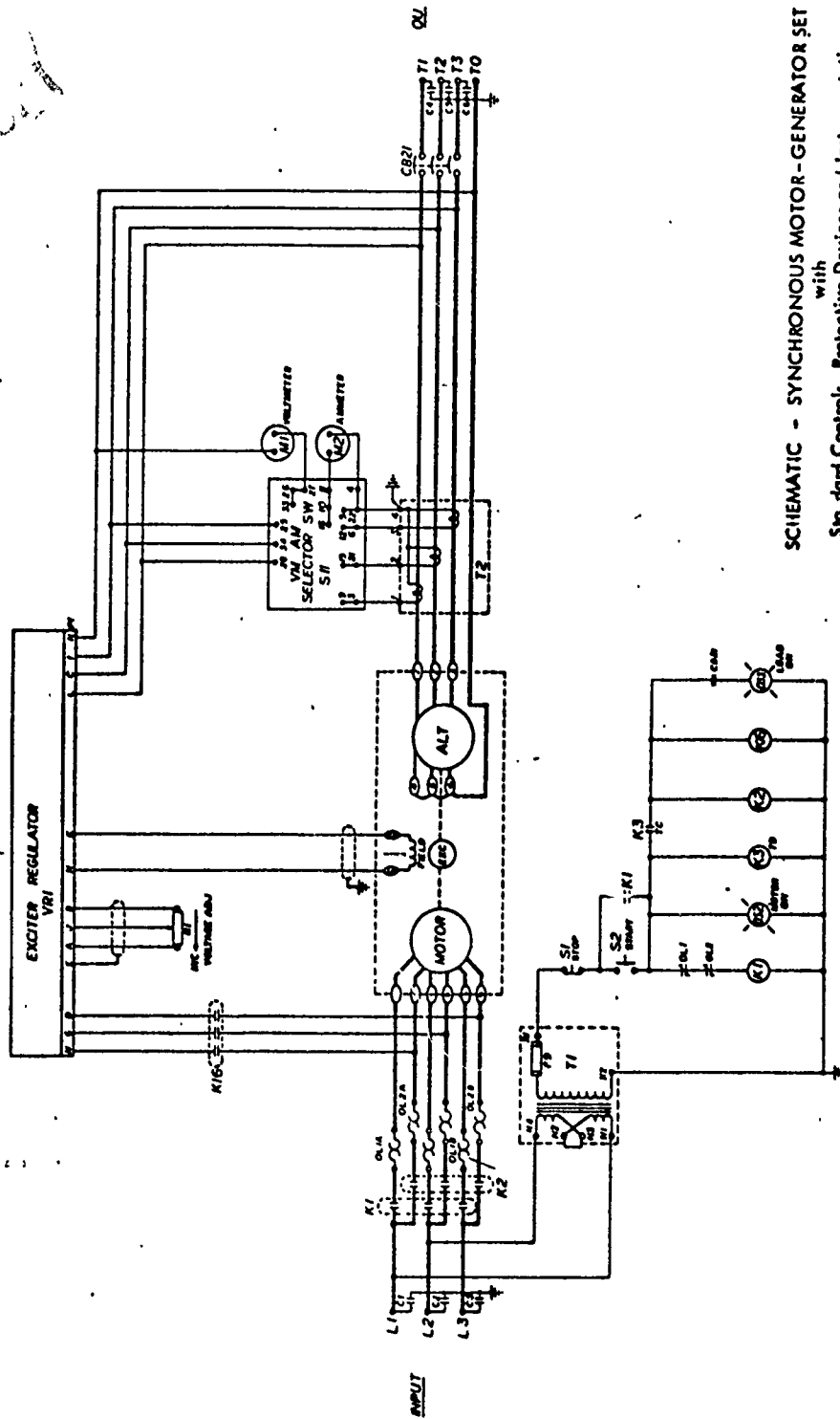
<u>HORIZONTAL MOTOR-GENERATOR</u>	<u>Indoor</u>		<u>Outdoor</u>	
	<u>Fixed</u>	<u>Mobile*</u>	<u>Fixed</u>	<u>Mobile</u>
<u>STANDARD INDOOR MODELS</u>				
Control cabinet - on same base as M-G	T	M		
Separate control cabinet - floor standing	F			
- wall mounting	W			
CONSOLE ENCLOSED - controls on front panel (Available to 100 KW)	C	CM	CO	
LOW-PROFILE SKID-MOUNTED (To 100 KW)	L		LO	
<u>VERTICAL MOTOR-GENERATOR (100 KW &amp; above)</u>				
Standard control cabinet - on same base as M-G	VF		VFO	
- for separate mounting	VFS		VFSO	
Console control cabinet - on same base as M-G	VC		VCO	
- for separate mounting	VCS		VCSO	
<u>HORIZONTAL M-G, MOBILE WEATHER-PROOF ENCLOSURE</u>				
Mounted on 4-wheel trailer				TR
Mounted on 4-wheel self-propelled truck				TM

\* Indoor Mobility - The motor-generator and control cabinet are mounted on a dolly with two fixed and two swivel casters, and tow-bar.

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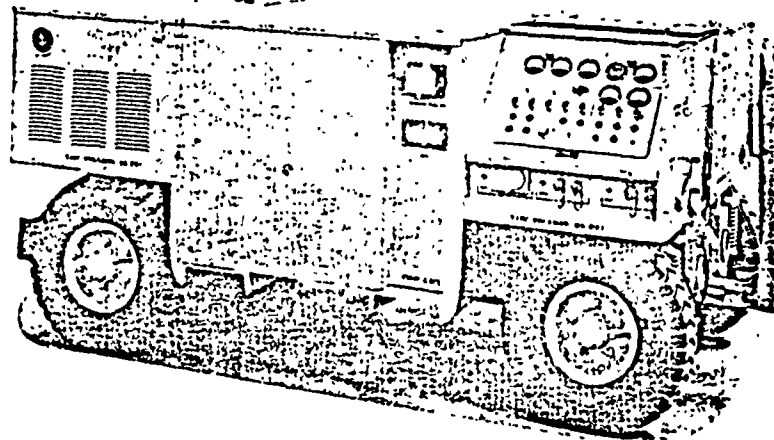


SCHEMATIC - SYNCHRONOUS MOTOR-GENERATOR SET  
with  
Standard Controls, Protective Devices and Instrumentation  
(Across-The-Line-Starting)



SCHEMATIC - SYNCHRONOUS MOTOR-GENERATOR SET  
with  
Standard Controls, Protective Devices and Instrumentation  
(Reduced Current Starting)

... PIONEERS IN PRECISE POWER **TECH/MEMO**



#### MMG-1A MOBILE POWER PLANT

The MMG-1A is a mobile electric power plant operating from 60 Hertz 3-phase input power to provide 60 KVA of 400 Hertz 3-phase precise power and 1000 amperes of 28 VDC precise power. It is designed and manufactured by Teledyne Inert in accordance with U.S. Navy Specification AS-1921, Rev. A, for the all-environment servicing and starting of U.S. Navy and Marine Corps aircraft on the flight line and in the hangar.

The MMG-1A represents the newest and highest standard of mobility, 400 Hertz and DC electrical power quality, reliability, and service life for aircraft ground power. Optionally, the power plant is available to operate from 50 Hertz 3-phase input power. Also up to 90 KVA of 400 Hertz power can be provided for either input frequency.

The power plant consists of an all-environment housing; mobile suspension; motor-generator; motor-generator controls and protective devices; solid-state DC power supply; DC power supply controls and protective devices; instrument and control panel; input and output cables.

The 60 to 400 Hertz motor-generator is synchronous, single-shaft, two-bearing; single-exciter, 1200 rpm. A solid-state package with four plug-in PC boards contains the voltage regulator, overvoltage, undervoltage, overfrequency, underfrequency and reverse phase sequence protection.

The M-G frame and end bells are iron castings. Bearings are oversized. Windings and lead insulations are Class H materials with the maximum operating temperature rise held below that of Class B materials. Dielectric strength is 5000 volts. Windings are protected with a combination of three special coats of varnish and epoxy.

The 60 Hertz to 28 VDC regulated power supply has six phase-controlled SCR's and a solid-state regulator and overvoltage protection. It is constructed on a flat panel for accessibility, and light weight. Windings are Class H material with three protective coatings.

The power plant housing and chassis are integral with independent articulated wheel suspension, pneumatic tires, mechanical brakes, latching tow bar, and lifting and tie-down rings. Hinged weatherproof doors and panels provide quick access.

cable, 30' DC output cable, manuals and tools.

The power plant meets MIL-STD-810 environmental conditions: operation from -40°C to +52°C, 100 percent humidity, rain, sand, fungus. Radio Frequency Interference (RFI) is suppressed in accordance with MIL-STD-461 and 462 over the frequency range of 150 KC to 150 MC.

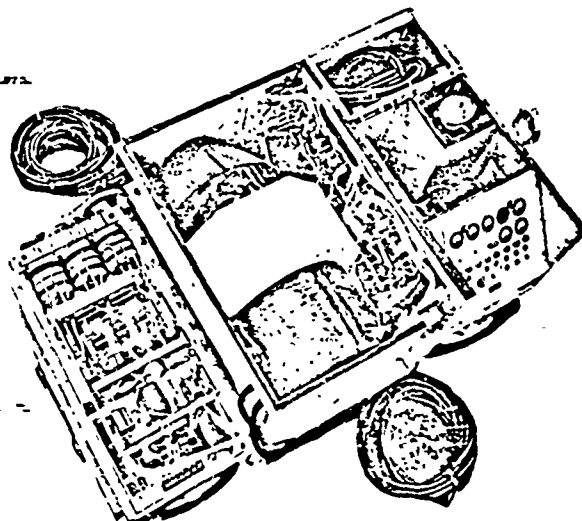
The power plant exceeds the requirements of MIL-M-008090E Type II Mobility. It is steerable with a 9' outside turning radius. It can be towed up to 20 mph over all types of terrain and 30 mph on paved roads. Brakes hold on a 28-degree slope.

#### Motor-Generator Electrical Performance

Input Power	220/440 volts, 60 Hz, 3-phase, 3-wire, 1.0 pf
Output Power	60 KVA, 400 Hz, 0.8 pf, 115/200 volts, 3-phase
Overload	140% for 3 minutes; 125% for 10 minutes
Efficiency	72%
Voltage Regulation	0.5%
Voltage Modulation	0.1%
Frequency Regulation	0.1%
Total Harmonics	1.5%
Transient Response	±22%
Transient Recovery	0.12 seconds
Phase Balance	0.5 volts
Current	*95 amps starting; 85 amps running

#### DC Power Supply Electrical Performance

Input Power	220/440 volts, 60 Hz, 3-phase, 3-wire, 1.0 pf
Output Power	28 VDC, 1000 amps for 5 min.; 500 amps continuous
Efficiency	80%
Voltage Regulation	0.1 volts
Ripple	0.8 volts
Transient Response	±21%
Transient Recovery	0.16 seconds



(4) Transformers, Voltage Regulators, Line Drop Compensators

<u>Mfr. Name</u>	<u>Response</u>	<u>Description</u>
GE	Yes	Letter dated October 5, 1976 - Sec. (1) - Irrelevant
Heavy-Duty (Sola)	Yes	Letter dated August 27, 1976 Irrelevant --does not produce this type of equipment.
Matra	No	-
Queensboro	Yes	Letter dated August 26, 1976 Irrelevant for this application.
Superior Electric Co.	No	-
Teledyne Crittenden	Yes	Letter dated September 7, 1976 Letter dated November 16, 1976
Teledyne Inet	Yes	Letter dated November 11, 1976



**HEVI-DUTY ELECTRIC**

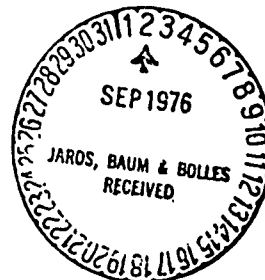
DIVISION OF SOLA BASIC INDUSTRIES

P.O. BOX 288 • GOLDSBORO, NORTH CAROLINA 27530 • PHONE 818-734-8800

August 27, 1976

Jaros, Baum & Booles  
1052 West Sixth Street  
Los Angeles, Calif. 90017

Attn: Mr. Paul Katzaroff



Ref: 60/400 HZ Study

Dear Mr. Katzaroff:

In answer to your letter of inquiry dated August 11, 1976, we find we are not in a position to provide a positive response. We have produced very few 400 HZ units and this area is not our major product area. After reviewing your requirements with our Engineering Department, we feel that our general product knowledge does not cover what you seek. The specs particularly on harmonic insertion and efficiency, we feel, are generally beyond our ability at this time. For your information, I am enclosing a bulletin describing in general our product scope.

Very truly yours,

HEVI-DUTY ELECTRIC DIV.  
Sola Basic Industries

R. H. Hambidge  
Manager -  
Specialty Products

RHH/lh

Enclosure

cc: R. D. Goodwin

## **Queensboro Transformer & Machinery Corporation**

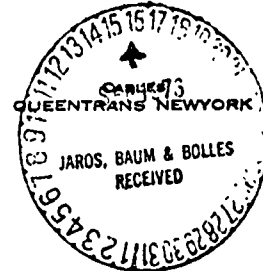
*Designers & Manufacturers of Power Transformers*

TELEPHONE  
(212) 461-5552

115-25 FIFTEENTH AVENUE  
COLLEGE POINT, NEW YORK 11356

August 26, 1976

Mr. Paul Katzaroff,  
Jaros, Baum & Bolles, Consulting Engineers  
1052 W 6 St  
Los Angeles, CA 90017



Re- Feasibility Stage Study  
Centralized 60/400 Hz Generation & distribution system

Gentlemen:

We thank you very much for your letter of Aug. 11, and we also refer to our telephone conversation of Aug. 16.

We start with answering your Questionnaire.

1. 28 years in the transformer manufacture.
2. 10 years in the Automatic Voltage Drop Compensator - Automatic Voltage Regulator manufacture.
3. 28 employees, incl. 3 graduated electrical engineers.
4. We manufacture 400 Hz transformers.
5. We did not manufacture, so far, 400 Hz regulators, but we see no difficulty.

To the best of our belief, ours - our incessant motion type Voltage Stabilizer is the only voltage correction apparatus on the world market, which does preclude computer errors.

6. So far, we have built dry and oil immersed voltage regulators up to 1,700 kVA, but we have the capability of building them up to 20 MVA. We have built regulating LTC (load tap change) furnace transformers up to 7 MVA.
7. As far the writer knows, we have never operated under MIL - Q - 9858 A, but we are willing to do so, even if it means an added bureacratic burden, provided that said extra paper work is sufficiently rewarded.

Now the budget prices, per unit, combination transformer with voltage stabilizer, dry type, 80°C, in a single enclosure, indoor, with built-on 4.16 kV oil fuse cutouts, with built flash into one of the panels (in the way shown on the enclosed photo B-525) LV molded case C/B, with emergency hand operation, with - 2.5% & + 2.5% "push for test" - quick checking feature, indicating and other instruments as described in the enclosed spec. We propose to have the stabilizer 3-phase, the transformer

in its secondary zigzag connected, which will give the same or better effect than 3 single phase regulators connected to a wye connected transformer secondary. According to our spec., we offer an accuracy of  $\pm 0.25\%$ , valid for the average voltage, valid for the rms voltage, valid for the peak voltage, and THEREFORE not inducing computer errors. A surge suppression circuit shall be built in.

<u>kVA</u>	<u>budget price</u>
30	\$31,000.
60	37,000.
90	49,000.
150	62,000.
300	115,000.
400	140,000.

Once again, these are units which make error-free operation of computers; if the requirement is lesser, or for a part of the apparatus needed lesses, then apparatus of a much lower price can be offered.

These apparatus hereabove are of our unique "incessant motion" type, a new invention which works very well at the Irving Trust Co., NYC. Before we developed this system, we applied the "three terminal" regulation, which is a slow control, but the wave is also strictly sinusoidal, and it has certain "dead band" (in the incessant regulation, the width of the dead band is zero). Nonetheless, all computer users of this system are very happy, among them the main computer center of the City of NY, and Payne Webber, Jackson & Curtis. These apparatus with 3-point regulation cost 1/3 to 1/4 of the above prices.

As mentioned, the above prices correspond to indoor apparatus. For outdoor, we would rather recommend oil immersed apparatus, 55°C rise, as we have e.g. built (5 transfer/regulators 300 & 500 kVA's) for the Riker's Island Penitentiary, NYC.~ If the Navy insists in the dry type, we have also built such, e.g. for the Police Launch Station #2, NYC; they have inside thermostatically controlled heating, the enclosures are double. It works alright, but oil is better. But oil or dry, please add \$1,500. (in the small sizes) to \$3,000. (large sizes) for outdoor.

We assume you wish us to give our critical review to your spec. We do it hereunder.

As we already described in conjunction with the equipment covered by our quotation, we would ~~rather~~ recommend to supply the transformer plus the regulator in a single enclosure. Of course there should be provision for separate removal of the transformer and/or the regulator by means of a crane or ~~overhead~~ overhead hoist. The HV section should be so enclosed that even after removal of LV panels, door opening etc., no access to HV parts be possible.

Now we are coming to an analysis of the Spec. in the order it was composed.

## TRANSFORMER

### To 1.-2.

We propose - just for Queensboro, and not for other prospective suppliers, 201/116 V zigzag in lieu of wye connected. For a transformer PROPERLY designed and built, the zigzag secondary ~~shall~~ shall limit the difference between phase voltages at any load unbalance to 1V max. and make it unnecessary to have 3 single phase voltage regulators.

There is much more to the art of designing and constructing zigzag transformers than just to make them with sec'y zigzag connections. Although everybody builds zigzag connected grounding autotransformers, there the task is an easy one and such an experience qualifies nobody to build zigzag 2-winding transformers. To the best of our knowledge, Queensboro is the only U.S. manufacturer with 2 winding transformer zigzag know-how.

### To 5.

As mentioned by phone, there occurred a small mistake in the spec. Also some other points should possibly be considered.

To begin with we are under the impression that not just the primary impedance could have been meant here, but the impedance. The impedance is the voltage which is measured on the primary (normally expressed in terms of percentage of the rated voltage) when the secondary is short-circuited, and the rated current flows through the primary.

The impedance is the geometric sum of the leakage reactance and of the effective resistance corrected to its reference temperature (in this case 100°C, not 25°C).

The leakage reactance is the algebraic sum of the primary reactance and the secondary reactance corrected by the reciprocal of the turn ratio. - The effective resistance is the algebraic sum of the primary 100°C ~~effective~~ effective resistance and the 110°C secondary effective resistance corrected by the reciprocal of the turn ratio. The term effective means the sum of the ohmic or d.c. resistance and the 400 Hz additional a.c. resistance, obtained from wattmeter reading of the total ~~2~~ I<sup>2</sup>R losses, and subsequent ~~separation~~ deduction of the I<sup>2</sup>R losses.

The impedance, be it total, be it just primary, apart from the slight temperature influence, is a constant and will not have one value for resistive loads, another for reactive loads. Thus we interpret the meaning of para. 5 of your spec. as follows:

"Transformer impedance at a test where secondary windings are "short circuited, shall be ~~the sum of~~ the "effective" (ohmic + "stray & eddy a.c.) resistance ~~plus~~, not exceeding 0.6%, plus the thereto geometrically added leakage resistance, whose "value must not exceed 3%.

From hereon we start to discuss this point.

As shown hereabove, we were able to interpret what para. 5 intends to express. This does not mean however that we are in agreement with these conditions; they are unnecessarily stringent - and possibly their compliance is not feasible at all. Moreover, the entire para. 5 with its whatever requirement it be, is, as we shall show ~~furth~~ further down, not necessary at all.

Let us start with the resistance, which is the sum of the resistances of the primary ~~xxxxxxx~~ and the adjusted secondary windings, and can be expressed in ohms, or in volts (as voltage drop), or per unit, or, as in most cases, as a percentage. As long as we speak about the ohmic resistance - the d.c. measured resistance, 0.6% is a moderate value, and no particular art is needed to achieve it. But for the entire effective resistance, 0.6% would be very difficult at 60 Hz, and is almost impossible to obtain at 400 Hz, as the eddy losses in Cu increase proportionally to the ~~fourth~~ <sup>second</sup> power of the frequency.

We would rather count with 1%.

Now the leakage ~~xxx~~ reactance for a 60 Hz transformer with no primary-to-secondary shielding - of 3% would be the "natural" value of a sound design.

The primary-to-secondary shielding plus its insulation increases the primary-to-secondary winding distance, which directly increases to leakage reactance.

Furthermore, for the same geometrical constellation, the higher the frequency, the greater is the magnitude of the leakage reactance.

We did not spent time, so far, in preparing of some trial designs of your particular transformers. It is possible that a 3% leakage reactance is achievable, if the design embodies very tall and very narrow core windows. Such a design would be not a "natural", its cost would be relatively very high. And because of the unnatural height of the core, the design would be connected with relatively very high iron losses, i.e. no-load losses, high magnetizing current, high inrush current.

Thus these conditions, if they can be met at all, can be met only by an uneconomical design, with high no-load loss, high exciting current, high inrush current. And what are the advantages, if these sacrifices are made? Only one: a relatively low transformer's own regulation, i.e. a relatively great stiffness in maintaining of an output voltage very close to the emf value.

This would have really been an advantage, if no regulator were added to the transformer. With the regulator added, it is of no importance at all, provided the apparatus own regulation is not completely "out of whack".

My advise is to omit para. 5 altogether. Rather specify in the regulator section a required NET voltage correction capacity for the total complex transformer incl. regulator.

Net voltage correction capacity means a correction capacity at ANY power factor and full load, in which the own voltage drop (regulation) in both the regulator as well as in the transformer has already been subtracted.

Our company is ~~guarant~~ specifying, ~~and~~ guaranteeing the net voltage correction capacity for every order, every job, at all the times.- But to the best of our knowledge we are the only company in the market ever to do so.

To 4.

The primary-to-secondary shield per se is an inexpensive item, yet due to the necessary added radial insulation, it causes some increase of transformer's general dimensions. Consequently, while it is to be inserted in applications where it is needed, it should be omitted where it is unnecessary.

In this particular project, it is necessary in those particular cases where one 400 Hz otherwise fully isolated generator supplies power to more than one transformer-regulator assembly.

In our opinion, it should be preferable to omit it, where one isolated 400 Hz generator feeds a single transformer-regulator assembly and absolutely no other load beyond that.

To 8. & 11.

Suggest to omit any impulse test. The operating voltage is here only 4160 V.

A prototype bolted short-circuit test of the transformer-regulator assembly may be of some value. The limits and the test spec. would have to be in such a case very carefully studied.

To 13. & 16.

For outdoor oil should be preferable to the dry type, for the transformer incl. the regulator. The life expectancy is higher, the cost of the periodic preventive maintenance lower, reliability higher.

By the way, we attach absolutely no value to the military way of calculation of the MTBF (mean time between failures) and MTR (mean time to repair), based on the failure ratio of the little electronic components, when they have to work in conjunction with power apparatus. Time and again we saw that sound engineering criteria gave a safer guidance.

To 14.

We suggest rather than having the oil fuse cutouts inside the apparatus enclosure, to have them mounted on the apparatus roof, ~~with~~ with the fuses being accessible from the outside; we have made it ~~as~~ even for the military (Bermuda) with very good result. Upon request we shall send you drawings etc.

The top oil fuse location is good for indoor and outdoor apparatus, for dry and oil-immersed apparatus. The cabling is inside of the apparatus. We would use G & W 5 kV, 3-pole ganged, 200 amp oil-fuse ~~xxxxxx~~ cutouts with a combination key interlock.

To 15

If our suggestion of combining the transformer and the regulator in a common enclosure is accepted, the preferable location of the C/B would be electrically at the regulator output (not the input).

The LV molded case C/B does not need a separate steel enclosure; we propose flush mounting on one of the regulator panels (see enclosed photos B-525)

V O L T A G E   R E G U L A T O R

To 1 to 5

We just wish to repeat what we proposed in our Remark to 5. for the Transformer.

We propose to combine the Transformer and the Voltage Regulator to a single apparatus, and to specify a minimum net correction capacity of 5% for the total assembly, at ANY load, ANY power factor, ANY load unbalance, for an ambient temperature, say, from +12°C to + 40°C for the indoor apparatus, and - 20°C to + 40°C for the outdoor apparatus.

This would combine EVERYTHING said in paragraphs 1-2-3-5 and provide you with more safety.

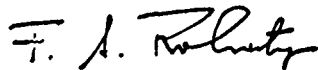
To 7.

Specifically, for Queensboro only, we propose to furnish a transformer zigzag connected in the LV, we propose to sense each individual load phase voltage, but to furnish a 3-phase regulator which will perform its regulation process according to the instantaneous AVERAGE ERROR of the 3 individual phase voltages. We can demonstrate this method and its great success in various places.

These are only critical remarks to the points contained in the Spec. We are to your disposal for a very detailed discussion of such points, like Cu for windings and leads for the transformer and the regulator; support of windings and leads; regulation accuracy; harmonics; accuracy of correction of the average, of the rms, of the peak voltage - why is it needed; phase shift made by the apparatus itself; all-over efficiency - transformer incl. regulator.

As mentioned over the phone, a lecture of mine, sponsored by the IEEE, arranged by your Mr. A. Dutko, will take place on Oct. 7, 76, at Stone & Webster's auditorium, 1 Penn Plaza, NYC. The lecture shall be on this subject, you are of course, cordially invited. It would be of very great value - certainly of value for this project, if you kindly could attend. We could then spend, say, a full day together, and go over detail by detail.

Cordially,



Frederick S. Rohatyn, MSEE, P.E.  
President

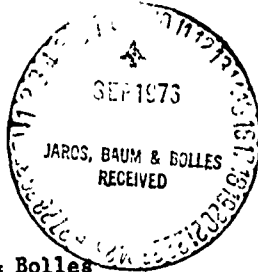
FSR:rz

So. Calif. Rep.: Marrs & Assocs, POB 698, La Mirada, CA 90637  
(213) 947-2095

Encls.: List of Clientele, Transformers & Reactors  
93 pages, not fully up to date)  
List of Clientele, Voltage Regulators  
Circular, program of manuf.  
Bul. 1000.1 (the picture does not conform to our today's  
apparatus, but the text is still valid,-  
-for buildings)  
Bul. 2000.1 - it might be of academic interest  
Reprint from March/Apr.72 ELECTRICAL CONSTRUCTION & MAINTEN.  
- Automatic Voltage Drop Compensation (for bldgs.)  
Photo B-531 - 225 kVA Computer Voltage Stabilizer  
installed at Irving Trust Co., NYC  
(2) Photos B-532 - to show our voltage regulator with  
built-in C/B  
Spec. Computer Voltage Stabilizer  
Automatic Voltage Drop Compensation for Computers - this  
was the intended start of an article on this  
subject, which is in preparation; it is only  
scribed, not well legible, incomplete, and not  
really good, but it is the only thing we can  
send in the meantime.- Please forgive. Something  
much better shall be available in the not too  
distant future.

 **TELEDYNE  
CRITTENDEN**

13011 S. SPRING STREET  
LOS ANGELES, CALIFORNIA 90081  
(213) 321-4355



September 7, 1976

Jaros, Baum & Bolles  
1052 West Sixth Street  
Los Angeles, California 90017

Attention: Mr. Paul Katzaroff  
RE: Your letter of 8-11-76, re: Feasibility Study  
Centralized 400hz Distribution System

Gentlemen:

Attached are three brochures illustrating some of the products we design and manufacture at Teledyne Crittenden.

Also attached are three drawings of 400 hertz transformers with primary O.F.C.'s and secondary breakers 60, 75 and 150 KVA for your information.

Following are budgetary prices on 400 hertz transformers with primary O.F.C.'s, secondary breakers and line drop compensators:

30 KVA = \$ 4,947.00	150 KVA = \$ 7,265.00
60 KVA = 5,410.00	300 KVA = 10,650.00
90 KVA = 6,415.00	400 KVA = 13,445.00

In regards to your specification outline for transformers:

Paragraph 5 -- we feel the second word should be regulation.

Paragraph 8 -- our dry type transformers are designed to NEMA and ANSI standards. The primary insulation between windings and winding to ground for 4160V units is 12000V. The impulse test is 25,000 Volts.

We are returning your questionnaire and I hope we have satisfactorily answered your questions and supplied you with useful data.

Sincerely,

TELEDYNE CRITTENDEN

  
Chuck Kinzy, Sales Manager

CK/mlp

# QUESTIONNAIRE TRANSFORMER/REGULATORS

- |   |                             |
|---|-----------------------------|
| 1. How many years in transformer business?  | <u>53</u>                   |
|   | <u>see 1</u>                |
| 2. How many years in AC regulator business? | <u>below</u>                |
| 3. How many employees?                      | <u>45</u>                   |
| 4. Do you manufacture 400 Hz transformers?  | <u>Yes</u>                  |
|   | <u>see 1</u>                |
| 5. Do you manufacture 400 Hz AC regulators? | <u>below</u>                |
|   | <u>see 1</u>                |
| 6. In what power capacities?                | <u>below</u>                |
|   | <u>Not</u>                  |
| 7. Do you operate under MIL-Q-9858A?        | <u>anymore</u> <sup>2</sup> |

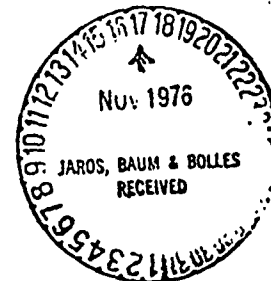
We will appreciate a customer list illustrating transformers or voltage regulators you have manufactured which are similar to those required in power rating, frequency of output, voltage of input or output.

1. When we need a line drop compensator, it is purchased from our sister company, Teledyne Inet, and installed in conjunction with our transformer. They have many years of experience in this field.
2. At one time Teledyne Crittend operated their Q.C. system in strict compliance with MIL-Q-9858A. We were also listed and approved by the Armed Services Electro Standards Agency to manufacture transformers to MIL-T-27A & B. However, as the demand dropped for this type of large transformer, we had to reduce the Q.C. system to be more compatible with the more competitive commercial transformers.
3. Following are a few facilities we have supplied with 400 hz transformers:

Hughes Aircraft Company  
 Douglas Aircraft Company  
 North American Rockwell  
 Leach Corporation  
 Teledyne Inet  
 Yuma Marine Corp Air Station  
 Naval Undersea Center, San Diego  
 Northrop Corporation  
 Naval Regional Procurement Office, Washington, D.C.  
 Litton Industries  
 Robin's A.F.B. Georgia  
 Defense Electronic Supply Center, Dayton, Ohio

**TELEDYNE  
CRITTENDEN**

13011 S. SPRING STREET  
LOS ANGELES, CALIFORNIA 90081  
(213) 321-4355



November 16, 1976

Jaros, Baum & Bolles  
1052 W. 6th Street  
Los Angeles, CA 90017

Attention: Mr. Donald Salyers (482-7676)

Reference: Your letter of 8-11-76 and phone conversation  
of this date.

Enclosure: 5 copies of our Brochure # 7-68.

Gentlemen:

We are pleased to re-quote the following budgetary prices  
on three phase 400 hertz dry type transformers only, for  
outdoor installation, 4160V input to 200Y/115V output,  
with electro-static shields.

30 KVA = \$1031.00	150 KVA = \$2862.00
60 KVA = \$1568.00	300 KVA = \$4695.00
90 KVA = \$1965.00	400 KVA = \$6228.00

Sincerely,

TELEDYNE CRITTENDEN

*Chuck Kinzy*  
Chuck Kinzy,  
Sales Manager

CC: Jim Vallily  
Teledyne Inet

CLASS "H"

Smaller Size • Lower Sound • Lighter Weight

## DRY TYPE TRANSFORMERS

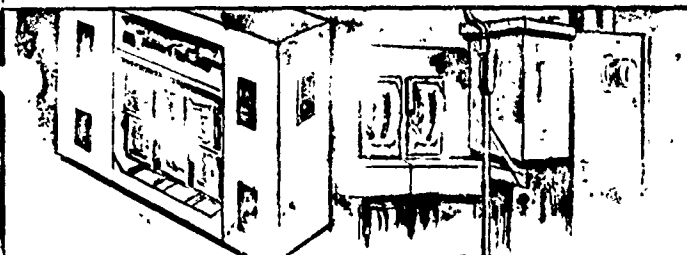
Lighting • Power • Distribution

by

*Crittenden*



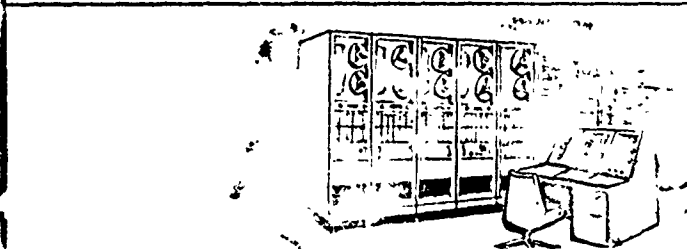
#7-68



for

- MILITARY
- INDUSTRIAL
- COMMERCIAL

application



13011 SO. SPRING ST. • LOS ANGELES, CALIFORNIA 90061 • 213-321-4355

# **DRY TYPE TRANSFORMERS**

## **For Lighting & Power Service**

### **PREFACE**

Since its establishment in 1923, Crittenden Transformers has provided the electrical and electronic industries with prompt and efficient attention to their transformer requirements.

Crittenden Transformers has an integrated quality control system to insure uniformity and dependability.

This quality control system meets MIL-Q-9858.

Crittenden transformers are of the highest quality, shipments are prompt, prices are reasonable, this means dependability and low cost operation to the user. Compare and judge for yourself.

We maintain a large stock of dry type transformers from 15KVA and upward, single and three phase, in the 480 volt class, for power and lighting.

The list prices in this catalog are for transformers enclosed in sheet metal cases, core and coil assemblies only, are available at a reduction in price.

For transformer applications other than illustrated in this catalog, see catalogs for "Power Saturable Reactors" and "Special Purpose Transformers." Our engineering department is ideally qualified to design all types of transformers for special purposes to customers specifications.

Write or phone your inquiries to the factory, Sales or Engineering departments.

## DRY TYPE TRANSFORMERS

For Lighting & Power Service

### DESIGN AND TEST SPECIFICATIONS

Design and test specifications for dry type transformers are in accordance with the following standards:

ASA C57.12-90 and ASA C57.12-00

NEMA TR1-0.01 thru TR1-0.47

Dry type transformer rated loads are in accordance with the nameplate ratings. For loads in excess of the nameplate ratings the following table shall apply. These values are conservative, and will give approximately the same life expectancy as though the transformer had been operated at rated load for the 24 hour period. If additional data is required, refer to ASA C57.96-01.250.

Daily Loads Above Rating to Give Normal Life Expectancy  
in 30°C Average Ambient

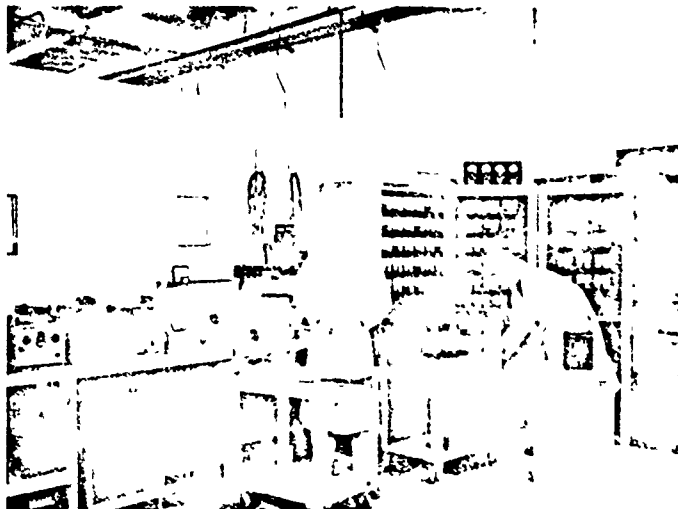
Peak Load Time in Hours	TIMES RATED KILOVOLT-AMPERES		
	Ventilated Self-Cooled		
	Following and Followed By a Constant Load Of		
	90 Percent	70 Percent	50 Percent
1/2	1.64	1.85	2.00
1	1.38	1.48	1.52
2	1.23	1.28	1.33
4	1.13	1.15	1.18
8	1.06	1.07	1.08

This manufacturer contends if a 10% continuous overload is to be specified, without reduction of life expectancy, this should be the rating stamped on the nameplate, not some lesser rating. Otherwise, if tests were to be performed, in accordance with NEMA and ASA standards, the nameplate rating will apply, not some greater value.

Certified test reports of basic transformer designs can be supplied upon request, at no charge. Test reports other than basic transformer designs can be supplied at an additional cost, this cost to be negotiated with the factory.

Basic impulse level. All Crittenden basic transformer designs are tested in our plant, with our impulse generator to ASA and NEMA standards.

Each unit is individually tested for voltage ratio - polarity - sound level - insulation breakdown between windings, and to core. Induced voltage test at 2 times normal voltage and 2 times the frequency for 7200 cycles.





**CRITTENDEN TRANSFORMER**

A TELEDYNE COMPANY

### TRANSFORMER CONSTRUCTION FEATURES

Cores are laminated from oriented non-ageing Electrical steel.

Coils are wound with high temperature film coated oxygen free copper conductors. Layer insulations are composed of fiber glass cloth, mica and asbestos.

Low sound levels are obtained by efficient core designs, plus internal vibration mounting, which isolates the core and coil assembly from the case. This also reduces transmission of vibration of building structures. Additional external vibration mounts are available upon request. Consult factory for prices.

Solderless compression lugs are supplied for ease of connection, and they are easily removable if larger sizes are required. These lugs are sized for the full load ampere rating of each unit. If oversized or special lugs are required, please consult factory.

Spacious wiring compartments are located at bottom of cases. Compartment temperatures will not exceed 30° C rise above ambient, allowing connection with TW cable.

All units are guaranteed against defective material or workmanship for one (1) year "from date of shipment." Defective units are to be returned prepaid to the factory. If factory inspection and tests confirm the unit defective, Crittenden will repair or replace the defective unit. Credit will then be issued to compensate for freight charges incurred because the unit was defective, and the repaired or replacement unit will be returned prepaid.

### COIL CONSTRUCTION

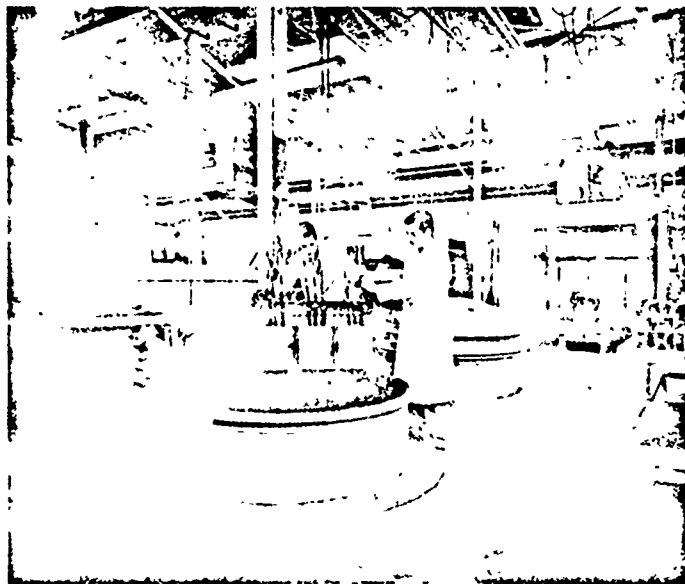
as designated by

ASA and NEMA STANDARDS

**Class "B"** - Insulated for 80° C. rise above 30° C. ambient. The materials used in this class are inorganic, such as fiber glass cloth, asbestos, mica and glass fiber insulated conductors, all bonded together with high temperature insulating varnishes.

**Class "F"** - Insulated for 115° C. rise above 30° C. ambient. This class requires materials similar to the class "B" type, except bonding varnish is class "F."

**Class "H"** - Insulated for 150° C. rise above 30° C. ambient. This class requires materials similar to the class "B" type, except the bonding substances are to be composed of silicone compounds. Rubbery or resinous forms of silicone compounds are also acceptable.



Vacuum impregnating - At Crittenden this process is standard procedure for impregnating all types of coils with the proper insulating varnish.

# DRY TYPE TRANSFORMERS

## For Lighting & Power Service



NEMA & ASA audible sound levels for self cooled, dry type transformers.

600 Volts or Less ASA C89.1 - 1961		15000 Volts to 600 Volts NEMA TRI-1962	
KVA	AVERAGE db 1 Foot From Case	KVA	AVERAGE db 1 Foot from Case
0-9	40	0-300	58
10-50	45	301-500	60
51-150	50	501-700	62
151-300	55	701-1000	64
301-500	60	1001-1500	65
		1501-2000	66
		2001-3000	68

CRITTENDEN Class "H" insulated, Quiet Type Transformers have sound levels of 40 db, 15 through 50 KVA, 45 db, 75 KVA through 150 KVA and 50 db through 500 KVA.

### USEFUL ELECTRICAL FORMULAS

DESIRED DATA	ALTERNATING CURRENT		
	SINGLE PHASE	TWO-PHASE* FOUR-WIRE	THREE-PHASE
Kilowatts	$\frac{I \times E \times P.F.}{1000}$	$\frac{I \times E \times 2 \times P.F.}{1000}$	$\frac{I \times E \times 1.73 \times P.F.}{1000}$
Kva.	$\frac{I \times E}{1000}$	$\frac{I \times E \times 2}{1000}$	$\frac{I \times E \times 1.73}{1000}$
Horsepower Output	$\frac{I \times E \times \% \text{Eff.} \times P.F.}{746}$	$\frac{I \times E \times 2 \times \% \text{Eff.} \times P.F.}{746}$	$\frac{I \times E \times 1.73 \times \% \text{Eff.} \times P.F.}{746}$
Ampere When Horsepower is Known	$\frac{H.P. \times 746}{E \times \% \text{Eff.} \times P.F.}$	$\frac{H.P. \times 746}{2 \times E \times \% \text{Eff.} \times P.F.}$	$\frac{H.P. \times 746}{1.73 \times E \times \% \text{Eff.} \times P.F.}$
Ampere When Kilowatts is Known	$\frac{K.W. \times 1000}{E \times P.F.}$	$\frac{K.W. \times 1000}{2 \times E \times P.F.}$	$\frac{K.W. \times 1000}{1.73 \times E \times P.F.}$
Ampere When Kva. is Known	$\frac{K.V.A. \times 1000}{E}$	$\frac{K.V.A. \times 1000}{2 \times E}$	$\frac{K.V.A. \times 1000}{1.73 \times E}$

\*In three-wire, two-phase circuits the current in the common conductor is 1.41 times that in either other conductor.

E = Volts. I = Amperes. % Eff. = Per Cent Efficiency. P.F. = Power Factor.

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

FULL LOAD AMPERES FOR SINGLE PHASE TRANSFORMERS  
AT THE FOLLOWING SPECIFIED VOLTAGES

KVA	120 V	240 V	277 V	480 V	2400 V	4160 V	4800 V
3	25	12.5	10.8	6.25	1.25	.72	.625
5	41.6	20.8	18.1	10.4	2.08	1.2	1.04
7½	62.5	31.25	27.1	15.63	3.125	1.8	1.563
10	83.3	41.65	36.1	20.83	4.165	2.41	2.083
15	125	62.5	54.1	31.25	6.25	3.6	3.125
20	166.5	83.25	72.1	41.6	8.325	4.82	4.16
25	208	104	90.2	52	10.4	6	5.2
37½	312	156	135	78	15.6	9	7.8
50	416	208	181	104	20.8	12	10.4
75	625	312.5	271	156.3	31.25	18	15.63
100	833	416.5	361	208.3	41.65	24.1	20.83
125	1040	520	451	260	52	30	26
150	1250	625	541	312.5	62.5	36.1	31.25
167½	1395	697.5	605	348.75	69.75	40.3	34.875
200	1666	833.5	723	416.5	83.3	48.2	41.65
250	2082	1041	903	520.5	104.11	60	52.05
333	2775	1387.5	1201	693.75	138.75	80	69.375
500	4160	2082	1805	1041	208.2	120.4	104.1



CRITTENDEN TRANSFORMER

ATELEDYNE COMPANY

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

FULL LOAD AMPERES FOR THREE PHASE TRANSFORMERS  
AT THE FOLLOWING SPECIFIED VOLTAGES

KVA	208 V	240 V	480 V	2400 V	4160 V	4800 V	7200 V	12000 V
5	13.9	12	6	1.2	.7	.6	.4	.24
7½	20.8	18.1	9.1	1.81	1.04	.91	.6	.361
9	25	21.7	10.8	2.17	1.25	1.08	.72	.434
15	41.6	36.1	18	3.61	2.08	1.8	1.2	.723
20	55.5	48.2	24.1	4.82	2.78	2.41	1.6	.965
25	69.4	60.2	30.1	6.02	3.47	3.01	2.01	1.2
30	83.3	72.2	36.1	7.22	4.16	3.61	2.4	1.45
37.5	104.2	90.2	45.2	9.02	5.2	4.52	3.01	1.8
45	125	108.1	54.1	10.81	6.25	5.41	3.61	2.17
50	139	120.2	60.1	12.02	6.95	6.01	4.02	2.42
75	208	180	90.1	18.1	10.4	9.01	6.02	3.61
100	278	240	120	24	13.9	12	8.02	4.82
112.5	312	271	135.5	27.1	15.6	13.55	9.03	5.42
150	416	361	180.5	36.1	20.8	18.05	12	7.22
200	555	482	241	48.2	27.8	24.1	16	9.63
225	625	541	271	54.1	31.2	27.1	18	10.8
250	695	602	301	60.2	34.7	30.1	20	12
300	833	722	361	72.2	41.6	36.1	24.1	14.5
500	1390	1202	601	120	69.5	60.1	40.2	24.2
750	2082	1804	902	181	104	90.2	60.2	36.1
1000	2780	2400	1200	240	139	120	80.2	48.2
1500	4160	3610	1805	361	208	180	120	72.2
2000	5550	4810	2410	481	278	241	160	96.3



CRITTENDEN TRANSFORMER

A TELEDYNE COMPANY

# 

For Lighting & Power Service

### 

	MAX. COPPER AMPS.	MIN. COPPER AMPS.	MAX. ALUM. AMPS.	MIN. ALUM. AMPS.	WIRE SIZES
SAU-70	70	15	60		#4 #14
SLU-70	80	40	70	30	#2 #8
SLU-125	125	90	100	80	#1/0 #2
SLU-225	200	90	150	80	#4/0 #2
SLU-300	275	125	225	100	#350 MCM #1/0
SLU-400	325	125	275	100	#500 MCM #1/0
LU-2	400	250	300	200	2-#4/0 2-#1/0
LU-4	550	250	450	200	2-#350 MCM 2-#1/0
LU-6	650	250	550	200	2-#500 MCM 2-#1/0
2 Pcs. TL-650P	1800	1300	1400	1100	4-#1000 MCM 4-#500 MCM



CRITTENDEN TRANSFORMER

A TELEDYNE COMPANY



CRITTENDEN TRANSFORMER

A TELEDYNE COMPANY

**ALLOWABLE CONTINUOUS CURRENT-CARRYING CAPACITIES  
OF COPPER CONDUCTORS IN AMPERES**

**Not More Than Three Conductors in Raceway or Cable  
(Based on Room Temperatures of 30°C. 86°F.)**

Size AWG MCM	CALIF.	NATIONAL CODE					
	Calif. State Code 1962	Rubber Type R W Type R U (14-6)	Rubber Type RH	Paper	Asbestos Var - Cam Type AVA Type AVL	Impreg- nated Asbestos Type AI (14-8) Type AIA	Asbestos Type A (14-8) Type AA
		Thermo- plastic Type T (14-4/O) Type TW (14-4/O)		Thermo- plastic Asbestos Type T A			
				Var - Cam Type V			
				Asbestos Var-Cam Type AVB			
14	15	15	15	25	30	30	30
12	20	20	20	30	35	40	40
10	30	30	30	40	45	50	55
8	40	40	45	50	60	65	70
6	50	55	65	70	80	85	95
4	70	70	85	90	105	115	125
3	80	80	100	105	120	130	145
2	90	95	115	120	135	145	165
1	100	110	130	140	160	170	190
0	125	125	150	155	190	200	225
00	150	145	175	185	215	230	230
000	175	165	200	210	245	265	285
0000	200	195	230	235	275	310	340
250	225	215	255	270	315	335	.....
300	250	240	285	300	345	380	.....
350	275	260	310	325	390	420	.....
400	300	280	335	360	420	450	.....
500	325	320	380	405	470	500	.....
600	.....	355	420	455	525	545	.....
700	.....	385	460	490	560	600	.....
750	400	400	475	500	580	620	.....
800	.....	410	490	515	600	640	.....
900	.....	435	520	555	.....	.....	.....
1,000	450	455	545	585	680	730	.....
1,250	.....	495	590	645	.....	.....	.....
1,500	.....	520	625	700	785	.....	.....
1,750	.....	545	650	735	.....	.....	.....
2,000	.....	560	665	775	840	.....	.....



CRITTENDEN TRANSFORMER

A TELEDYNE COMPANY

### TEMPERATURE CONVERSION TABLE

To use the table, look for the temperature reading we have in the middle column. If the reading you have is in degrees Centigrade, read the Fahrenheit equivalent in the right hand column. If the reading you have is in degrees Fahrenheit, read the Centigrade equivalent in the left hand column.

-80 to 34			35 to 77			78 to 290		
C		F	C		F	C		F
-62	-80	-112	1.7	35	95.0	25.6	78	172.4
-57	-70	-94	2.2	36	96.8	26.1	79	174.2
-51	-60	-76	2.8	37	98.6	26.7	80	176.0
-46	-50	-58	3.3	38	100.4	27.2	81	177.8
-40	-40	-40	3.9	39	102.2	27.8	82	179.6
-34	-30	-22	4.4	40	104.0	28.3	83	181.4
-29	-20	-4	5.0	41	105.8	28.9	84	183.2
-23	-10	14	5.6	42	107.6	29.4	85	185.0
-17.8	0	32	6.1	43	109.4	30.0	86	186.8
-17.2	1	33.8	6.7	44	111.2	30.6	87	188.6
-16.7	2	35.6	7.2	45	113.0	31.1	88	190.4
-16.1	3	37.4	7.8	46	114.8	31.7	89	192.2
-15.6	4	39.2	8.3	47	116.6	32.2	90	194.0
-15.0	5	41.0	8.9	48	118.4	32.8	91	195.8
-14.4	6	42.8	9.4	49	120.2	33.3	92	197.6
-13.9	7	44.6	10.0	50	122.0	33.9	93	199.4
-13.3	8	46.4	10.6	51	123.8	34.4	94	201.2
-12.8	9	48.2	11.1	52	125.6	35.0	95	203.0
-12.2	10	50.0	11.7	53	127.4	35.6	96	204.8
-11.7	11	51.8	12.2	54	129.2	36.1	97	206.6
-11.1	12	53.6	12.8	55	131.0	36.7	98	208.4
-10.6	13	55.4	13.3	56	132.8	37.2	99	210.2
-10.0	14	57.2	13.9	57	134.6	37.8	100	212.0
-9.4	15	59.0	14.4	58	136.4	43	110	230
-8.9	16	60.8	15.0	59	138.2	49	120	248
-8.3	17	62.6	15.6	60	140.0	54	130	266
-7.8	18	64.4	16.1	61	141.8	60	140	284
-7.2	19	66.2	16.7	62	143.6	66	150	302
-6.7	20	68.0	17.2	63	145.4	71	160	320
-6.1	21	69.8	17.8	64	147.2	77	170	338
-5.6	22	71.6	18.3	65	149.0	82	180	356
-5.0	23	73.4	18.9	66	150.8	88	190	374
-4.4	24	75.2	19.4	67	152.6	93	200	392
-3.9	25	77.0	20.0	68	154.4	99	210	410
-3.3	26	78.8	20.6	69	156.2	100	212	413.6
-2.8	27	80.6	21.1	70	158.0	104	220	428
-2.2	28	82.4	21.7	71	159.8	110	230	446
-1.7	29	84.2	22.2	72	161.6	116	240	464
-1.1	30	86.0	22.8	73	163.4	121	250	482
-0.6	31	87.8	23.3	74	165.2	127	260	500
-0.0	32	89.6	23.9	75	167.0	132	270	518
0.6	33	91.4	24.4	76	168.8	138	280	536
1.1	34	93.2	25.0	77	170.6	143	290	554

Formulas -  $C = 5/9 (F - 32)$  or  $F = 9/5 C + 32$

# DRY TYPE TRANSFORMERS

Class B Insulated 80°C Rise



## AUTO STARTER TRANSFORMERS

### NEMA MEDIUM DUTY

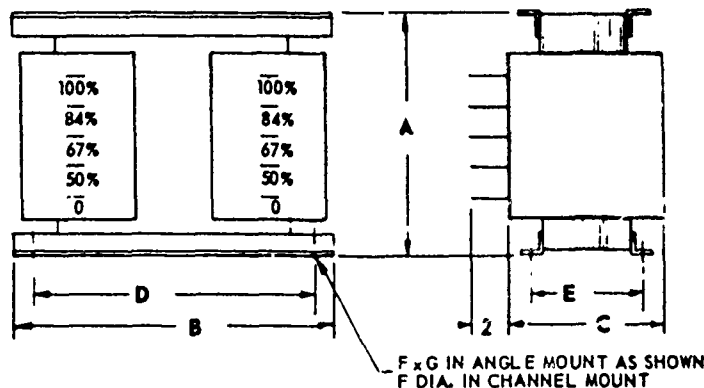
### 2 COIL OPEN DELTA TYPE

50/67/84/ 100% TAPS

208 or 240 or 480 VOLTS-3 PHASE-60 CYCLES

HORSE POWER	LIST PRICE	DIMENSIONS							WT.
		A	B	C	D	E	F	G	
10	148.00	6 3/4	10 1/2	6 3/4	9 1/2	4-1/4	9/32 x 9/16		50
15	171.00	6 3/4	10 1/2	7 1/4	9 1/2	4-5/8	9/32 x 9/16		54
20	188.00	6 3/4	10 1/2	7 1/2	9 1/2	4-7/8	9/32 x 9/16		58
25	207.00	6 3/4	10 1/2	8	9 1/2	5-3/8	9/32 x 9/16		62
30	229.00	8 1/4	11 1/2	8 3/8	10 1/2	5	11/32 x 11/16		75
40	272.00	8 1/4	11 1/2	8 3/4	10 1/2	5-3/8	11/32 x 11/16		98
50	320.00	9 1/4	11 1/2	9	10 1/2	6	11/32 D.	CHANNEL MOUNT NOT SHOWN	120
60	368.00	12	14	9	12	6	11/32 D.		140
75	408.00	13 1/4	15	9 1/2	13	6	13/32 D.		160
100	457.00	13 3/4	16	9 3/4	14	6 1/2	13/32 D.		238
125	492.00	14	16	10	14	6 1/2	13/32 D.		248
150	518.00	14 1/4	16 1/2	10 1/4	14 1/2	7	13/32 D.		260
200	550.00	15 1/2	16 1/2	10 1/2	14 1/2	7	13/32 D.		279
250	622.00	17	17 1/2	11	15 1/2	7 1/2	13/32 D.		298
300	718.00	17 3/4	20 1/4	12 1/4	18 1/4	8 1/2	13/32 D.		365
350	761.00	19 1/2	20 3/4	13 1/2	18	10 1/2	15/32 D.		420
400	838.00	21	22	14 1/2	20	10 1/2	15/32 D.		490
450	936.00	23	22	15 1/2	20	10 1/2	15/32 D.		545
500	1076.00	25 1/2	24	17 1/2	22	11 1/2	15/32 D.		600

Prices and dimensions subject to change without notice.



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For Lighting & Power Service

Class H Insulated 150°C Rise

For Indoor Installation

For Outdoor Installation specify w/P Shields

For Wall Mounting Brackets see Page 24



### 

KVA	PRIMARY VOLTAGE	SECONDARY VOLTAGE	LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	240/480	120/240	\$388	60.4	AA	160
20	240/480	120/240	447	60.4	AA	172
25	240/480	120/240	536	60.4	AA	210
30	240/480	120/240	583	60.4	AA	230
37½	240/480	120/240	635	60.5	AA	320
50	240/480	240/120	825	63	AB	430
75	240/480	240/120	1030	61	AB	600
100	240/480	240/120	1260	61	AB	732
150	240/480	240/120	1740	64	AB	1087
167½	240/480	240/120	2037	64	AB	1132

See Pages 22 and 23

### 

480 - OR - 240 TO 120/240 or 240/120 - 60 Cycle

KVA	LIST PRICE	SECONDARY VOLTAGE		CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
		3 WIRE	4 WIRE			
15	\$412		120/240	60.4	CA	160
20	477		120/240	60.4	CA	172
25	559		120/240	60.4	CA	210
30	617		120/240	60.4	CA	320
37½	718		120/240	60.5	CA	320
50	863	240/120		63	DB	430
75	1105	240/120		61	DB	600
100	1281	240/120		61	DB	732
150	1850	240/120		64	DB	1087
167½	2139	240/120		64	DB	1132

Prices subject to change without notice.

See Pages 22 and 23

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise



For Indoor Installation

For Outdoor Installation Specify W/P Shields

For Wall Mounting Brackets see Page 24

## SINGLE PHASE – NO TAPS

2400/4160 to 120/240 or 240/480 Volts – 60 Cycle

KVA	LIST PRICE	SECONDARY VOLTAGE		CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
		3 WIRE	4 WIRE			
15	\$412		120/240 240/480	60.4	A	170
20	477		120/240 240/480	60.4	A	190
25	559		120/240 240/480	60.4	A	215
30	617		120/240 240/480	60.5	A	285
37½	718		120/240 240/480	60.5	A	355
50	863	240/120	240/480	61	B or A	534
75	1105	240/120	240/480	61	B or A	644
100	1381	240/120	240/480	54	B or A	802
150	1850	240/120	240/480	64	B or A	1095
167½	2139	240/120	240/480	64	B or A	1140

See Pages 22 and 23

## SINGLE PHASE – TAPPED 2-2½% FCAN & 4-2½% FCBN

2400/4160 to 120/240 or 240/120 or 240/480 Volts – 60 Cycle

KVA	LIST PRICE	SECONDARY VOLTAGE		CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
		3 WIRE	4 WIRE			
15	\$432		120/240 240/480	60.4	CA	170
20	495		120/240 240/480	60.4	CA	190
25	585		120/240 240/480	60.4	CA	215
30	647		120/240 240/480	60.5	CA	285
37½	748		120/240 240/480	60.5	CA	355
50	903	240/120	240/480	61	DB or DA	534
75	1175	240/120	240/480	61	DB or DA	644
100	1425	240/120	240/480	54	DB or DA	802
150	1950	240/120	240/480	64	DB or DA	1095
167½	2210	240/120	240/480	64	DB or DA	1140

Prices subject to change without notice.

See Pages 22 and 23

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise



For Indoor Installation

For Outdoor Installation Specify W/P Shields

For Wall Mounting Brackets See Page 24

## SINGLE PHASE - NO TAPS

4160 to 120/240 or 240/120 or 240/480 Volts - 60 Cycle

KVA	LIST PRICE	SECONDARY VOLTAGE		CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
		3 WIRE	4 WIRE			
15	\$442		120/240 240/480	60.4	A	170
20	495		120/240 240/480	60.4	A	190
25	594		120/240 240/480	60.4	A	215
30	650		120/240 240/480	60.5	A	285
37½	763		120/240 240/480	60.5	A	355
50	900	240/120	240/480	61	B or A	534
75	1172	240/120	240/480	61	B or A	644
100	1440	240/120	240/480	54	B or A	802
150	1955	240/120	240/480	64	B or A	1095
167½	2171	240/120	240/480	64	B or A	1140

See Pages 22 and 23

## SINGLE PHASE - TAPPED 2-2½% FCAN & 4-2½% FCBN

4160 to 120/240 or 240/120 or 240/480 Volts - 60 Cycle

KVA	LIST PRICE	SECONDARY VOLTAGE		CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
		3 WIRE	4 WIRE			
15	\$456		120/240 240/480	60.4	CA	170
20	511		120/240 240/480	60.4	CA	190
25	613		120/240 240/480	60.4	CA	215
30	675		120/240 240/480	60.5	CA	285
37½	787		120/240 240/480	60.5	CA	355
50	946	240/120	240/480	61	DB or DA	534
75	1232	240/120	240/480	61	DB or DA	644
100	1510	240/120	240/480	54	DB or DA	802
150	2050	240/120	240/480	64	DB or DA	1095
167½	2281	240/120	240/480	64	DB or DA	1140

Prices subject to change without notice.

See Pages 22 and 23

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise



For Indoor Installation

For Outdoor Installation Specify W/P Shields

For Wall Mounting Brackets See Page 24

## SINGLE PHASE - NO TAPS

4800 to 120/240 or 240/120 or 240/480 Volts - 60 Cycle

KVA	LIST PRICE	SECONDARY VOLTAGE			CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
		3 WIRE	4 WIRE				
15	\$442		120/240	240/480	60.4	A	170
20	495		120/240	240/480	60.4	A	190
25	594		120/240	240/480	60.4	A	215
30	650		120/240	240/480	60.5	A	285
37½	763		120/240	240/480	60.5	A	355
50	900	240/120		240/480	61	B or A	534
75	1172	240/120		240/480	61	B or A	644
100	1440	240/120		240/480	54	B or A	802
150	1955	240/120		240/480	64	B or A	1095
167½	2171	240/120		240/480	64	B or A	1140

See Pages 22 and 23

## SINGLE PHASE - TAPPED 2-2½% FCAN & 4-2½% FCBN

4800 to 120/240 or 240/120 or 240/480 Volts - 60 Cycle

KVA	LIST PRICE	SECONDARY VOLTAGE			CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
		3 WIRE	4 WIRE				
15	\$456		120/240	240/480	60.4	CA	170
20	511		120/240	240/480	60.4	CA	190
25	613		120/240	240/480	60.4	CA	215
30	675		120/240	240/480	60.5	CA	285
37½	787		120/240	240/480	60.5	CA	355
50	946	240/120		240/480	61	DB or DA	534
75	1232	240/120		240/480	61	DB or DA	644
100	1510	240/120		240/480	54	DB or DA	802
150	2050	240/120		240/480	64	DB or DA	1095
167½	2281	240/120		240/480	64	DB or DA	1140

Prices subject to change without notice.

See Pages 22 and 23



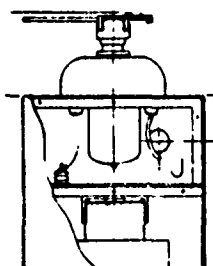
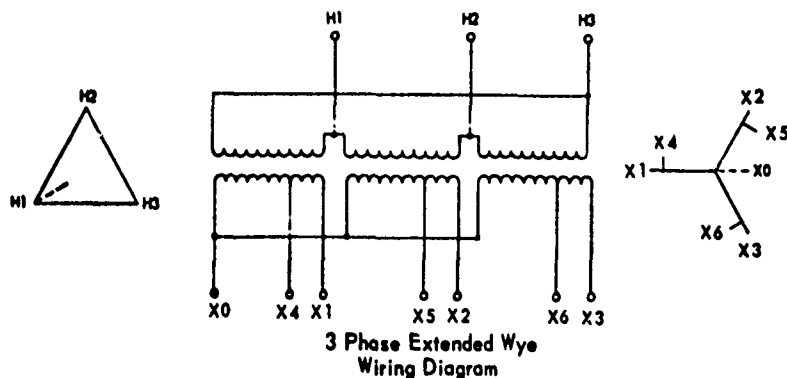
**CRITTENDEN TRANSFORMER**

**ATELEDYNE COMPANY**

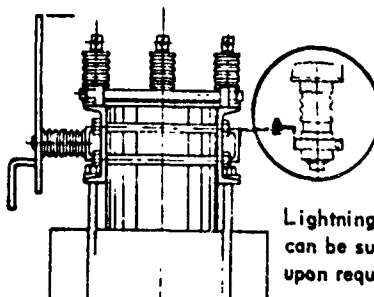
## SPECIAL APPLICATIONS

### EXTENDED WYE TRANSFORMERS

When a 240 volt three phase power load is also required from a 208Y/120 volt lighting transformer, the extended wye can be supplied, (see diagram below), at an additional cost of 5%.



Oil Fused Cutouts can be mounted in top of transformer case. Single or three-phase.  
See page 26

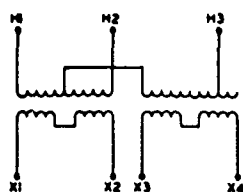


Lightning Arrestors can be supplied upon request.

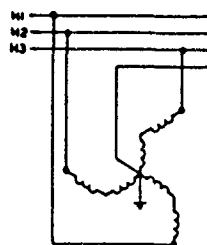
The impulse strength of Dry Type transformers is less than that of liquid-immersed units of the same voltage class. If there is any likelihood that transformers will be exposed to lightning or severe switching surges, adequate protective equipment must be provided.

### SCOTT T OR THE ZIG ZAG

Grounding Transformer can be supplied upon request.  
Please call or write the factory for technical data and prices.



Scott T 3-2 Phase  
Wiring Diagram



Zig-Zag Wiring  
Diagram

# 

For Lighting & Power Service

Class H Insulated 150°C Rise

For Indoor Installation

For Outdoor Installations Specify W/P Shields

For Wall Mounting Brackets See Page 24



### 

480 to 240 Volts - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½ FCAN & 4-2½ FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$411	\$440	44	G or H	220
20	525	556	44	G or H	275
25	615	646	43	G or H	337
30	708	744	43	G or H	353
37½	846	890	42	G or H	440
45	967	1015	42	G or H	484
50	1074	1130	42	G or H	512
75	1300	1365	41	G or H	726
100	1500	1572	49	G or H	976
112½	1600	1680	49	G or H	1020
150	2200	2300	48	G or H	1210
200	2450	2575	45	G or H	1732
225	2630	2760	45	G or H	1800
250	2800	2940	45	G or H	1875
300	3300	3500	46A	G or H	2154
500		6400	47A	H	3000
750		8160	52	H	4035

See Pages 22 and 23

### 

480 or 240 Delta to 208Y/120 or 480Y/277 - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½ FCAN & 4-2½ FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$411	\$440	44	E or F	220
20	525	556	44	E or F	275
25	615	646	43	E or F	337
30	708	744	43	E or F	353
37½	846	890	42	E or F	440
45	967	1015	42	E or F	484
50	1074	1130	42	E or F	512
75	1300	1365	41	E or F	726
100	1500	1572	49	E or F	976
112½	1600	1680	49	E or F	1020
150	2200	2300	48	E or F	1210
200	2450	2575	45	E or F	1732
225	2630	2760	45	E or F	1800
250	2800	2940	45	E or F	1875
300	3300	3500	46A	E or F	2154
500		6400	47A	F	3000
750		8160	52	F	4035

Prices subject to change without notice.

See Pages 22 and 23

# 

For Lighting & Power Service

Class H Insulated 150°C Rise  
For Indoor Installation



For Outdoor Installation Specify W/P Shields

For Wall Mounting Brackets See Page 24

### NO TAPS - THREE PHASE - TAPPED

4160/2400 to 240 or 480 Delta - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$ 530	\$ 557	43	I or J	270
20	634	665	43	I or J	294
25	792	823	42	I or J	366
30	900	936	42	I or J	397
37½	1078	1120	65	I or J	440
45	1206	1250	65	I or J	484
50	1250	1300	65	I or J	512
75	1520	1580	49	I or J	748
100	1780	1850	48	I or J	1000
112½	1950	2030	48	I or J	1092
150	2400	2495	53	I or J	1285
200	2850	2960	50	I or J	1875
225	3105	3230	50	I or J	1925
250	3280	3410	51	I or J	2010
300	3961	4170	51	I or J	2365
500		6570	47A	J	3288
750		8520	52	J	4465
1000		10590	.... Refer to factory ....		

See Pages 22 and 23

### NO TAPS - THREE PHASE - TAPPED

2400 Delta to 208Y/120 or 480Y/277 - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$ 530	\$ 557	44	E or F	220
20	634	665	44	E or F	275
25	792	823	43	E or F	337
30	900	936	43	E or F	353
37½	1078	1120	42	E or F	440
45	1206	1250	42	E or F	484
50	1250	1300	42	E or F	512
75	1520	1580	41	E or F	726
100	1780	1850	49	E or F	976
112½	1950	2030	49	E or F	1070
150	2400	2495	48	E or F	1210
200	2850	2960	45	E or F	1732
225	3105	3230	45	E or F	1800
250	3280	3410	45	E or F	1875
300	3961	4170	46A	E or F	2154
500		6570	47A	F	3000
750		8520	52	F	4035
1000		10590	.... Refer to factory ....		

Prices subject to change without notice.

See Pages 22 and 23

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise

For Indoor Installation



For Outdoor Installation Specify W/P Shields

For Wall Mounting Brackets See Page 24

## NO TAPS - THREE PHASE - TAPPED 4160 Delta to 240 or 480 Delta - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½ FCAN & 4-2½ FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$630	\$648	43	G or H	270
20	780	802	43	G or H	294
25	910	937	42	G or H	366
30	1045	1075	42	G or H	397
37½	1177	1210	65	G or H	440
45	1298	1335	65	G or H	484
50	1442	1485	65	G or H	512
75	1742	1795	49	G or H	748
100	2048	2105	48	G or H	1000
112½	2304	2375	48	G or H	1092
150	2790	2870	53	G or H	1285
200	3250	3350	50	G or H	1875
225	3380	3490	50	G or H	1925
250	3760	3870	51	G or H	2010
300		4389	51	H	2365
500		6800	47A	H	3288
750		8946	52	H	4465
1000		11120	Refer	H	Refer
1500		14300	to	H	to
2000		18350	Factory	H	Factory
2500		24400		H	

See Pages 22 and 23

## NO TAPS - THREE PHASE - TAPPED 4160 Delta to 208Y/120 or 480Y/277 - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½ FCAN & 4-2½ FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$630	\$648	43	E or F	270
20	780	802	43	E or F	294
25	910	937	42	E or F	366
30	1045	1075	42	E or F	397
37½	1177	1210	65	E or F	440
45	1298	1335	65	E or F	484
50	1442	1485	65	E or F	512
75	1742	1795	49	E or F	748
100	2048	2105	48	E or F	1000
112½	2304	2375	48	E or F	1092
150	2790	2870	53	E or F	1285
200	3250	3350	50	E or F	1875
225	3380	3490	50	E or F	1925
250	3760	3870	51	E or F	2010
300		4389	51	F	2365
500		6800	47A	F	3288
750		8946	52	F	4465
1000		11120	Refer	F	Refer
1500		14300	to	F	to
2000		18350	Factory	F	Factory
2500		24400		F	

Prices subject to change without notice.

See Pages 22 and 23

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise

For Indoor Installation

For Outdoor Installation Specify W/P Shields

For Wall Mounting Brackets See Page 24



## NO TAPS - THREE PHASE - TAPPED

4800 Delta to 240 or 480 Delta - 60 Cycle

KVA	NO TAPS UNIT PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$ 630	\$ 648	43	G or H	270
20	780	802	43	G or H	294
25	910	937	42	G or H	366
30	1045	1075	42	G or H	397
37½	1177	1210	65	G or H	440
45	1298	1335	65	G or H	484
50	1442	1485	65	G or H	512
75	1742	1795	49	G or H	748
100	2048	2105	48	G or H	1000
112½	2304	2375	48	G or H	1092
150	2790	2870	53	G or H	1285
200	3250	3350	50	G or H	1875
225	3380	3490	50	G or H	1925
250	3760	3870	51	G or H	2010
300		4389	51	H	2365
500		6800	47A	H	3288
750		8946	52	H	4465
1000		11120	Refer	H	Refer
1500		14300	to	H	to
2000		18350	Factory	H	Factory
2500		24400		H	

See Pages 22 and 23

## NO TAPS - THREE PHASE - TAPPED

4800 Delta to 208Y/120 or 480Y/277 - 60 Cycle

KVA	NO TAPS UNIT PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
15	\$ 630	\$ 648	43	E or F	270
20	780	802	43	E or F	294
25	910	937	42	E or F	366
30	1045	1075	42	E or F	397
37½	1177	1210	65	E or F	440
45	1298	1335	65	E or F	484
50	1442	1485	65	E or F	512
75	1742	1795	49	E or F	748
100	2048	2105	48	E or F	1000
112½	2304	2375	48	E or F	1092
150	2790	2870	53	E or F	1285
200	3250	3350	50	E or F	1875
225	3380	3490	50	E or F	1925
250	3760	3870	51	E or F	2010
300		4389	51	E or F	2365
500		6800	47A	F	3288
750		8946	52	F	4465
1000		11120	Refer	F	Refer
1500		14300	to	F	to
2000		18350	Factory	F	Factory
2500		24400		F	

Prices subject to change without notice.

See Pages 22 and 23

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise

For Indoor Installation Only



## NO TAPS - THREE PHASE - TAPPED

12000 to 240 or 480 Delta - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
112½	\$2800	\$2880	REFER TO FACTORY	G or H	REFER TO FACTORY
150	3300	3400		G or H	
200	4000	4120		G or H	
225	4300	4430		G or H	
250	4500	4630		G or H	
300	5000	5150		G or H	
500		7350		H	
750		10600		H	
1000		12500		H	
1500		14900		H	
2000		18900	REFER TO FACTORY	H	REFER TO FACTORY
2500		25800		H	
3000		31500		H	
3750		42000		H	
5000		52500		H	

See Pages 22 and 23

## NO TAPS - THREE PHASE - TAPPED

12000 Delta to 208Y/120 or 480Y/277 - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
112½	\$2800	\$2880	REFER TO FACTORY	E or F	REFER TO FACTORY
150	3300	3400		E or F	
200	4000	4120		E or F	
225	4300	4430		E or F	
250	4500	4630		E or F	
300	5000	5150		E or F	
500		7350		F	
750		10600		F	
1000		12500		F	
1500		14900		F	
2000		18900	REFER TO FACTORY	F	REFER TO FACTORY
2500		25800		F	
3000		31500		F	
3750		42000		F	
5000		52500		F	

Prices subject to change without notice.

See Pages 22 and 23

# 

For Lighting & Power Service

Class H Insulated 150°C Rise



For Indoor Installation Only

### 

13200 to 240 or 480 Delta - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
112½	\$2800	\$2880	REFER TO FACTORY	G or H	REFER TO FACTORY
150	3300	3400		G or H	
200	4000	4120		G or H	
225	4300	4430		G or H	
250	4500	4630		G or H	
300	5000	5150		G or H	
500		7350		H	
750		10600		H	
1000		12500		H	
1500		14900		H	
2000		18900		H	
2500		25800		H	
3000		31500		H	
3750		42000		H	
5000		52500		H	

See Pages 22 and 23

### 

13200 Delta to 208Y/120 or 480Y/277 - 60 Cycle

KVA	NO TAPS LIST PRICE	2-2½% FCAN & 4-2½% FCBN LIST PRICE	CASE NO.	WIRING DIAGRAM	APPROX. WEIGHT
112½	\$2800	\$2880	REFER TO FACTORY	E or F	REFER TO FACTORY
150	3300	3400		E or F	
200	4000	4120		E or F	
225	4300	4430		E or F	
250	4500	4630		E or F	
300	5000	5150		E or F	
500		7350		F	
750		10600		F	
1000		12500		F	
1500		14900		F	
2000		18900		F	
2500		25800		F	
3000		31500		F	
3750		42000		F	
5000		52500		F	

Prices subject to change without notice.

See Pages 22 and 23

# DRY TYPE TRANSFORMERS

For Lighting & Power Service

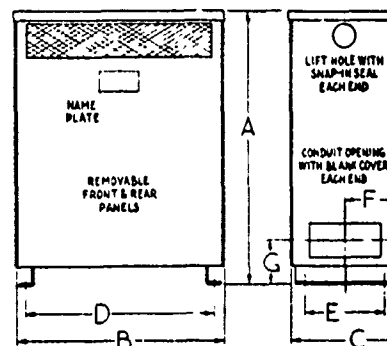
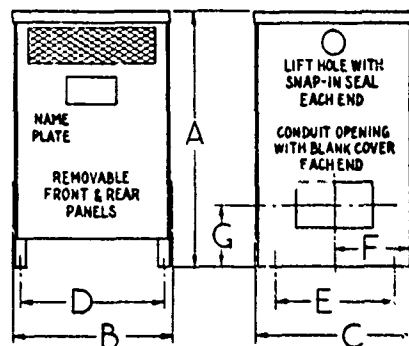
Class H Insulated 150°C Rise



ALL DIMENSIONS ARE IN INCHES

CASE NO.	OVERALL DIMENSIONS			MOUNTING DIMENSIONS		MOUNTING HOLES	CONDUIT OPENINGS		
	A	B	C	D	E		Size	F	G
41	33 3/4	29 3/4	20 3/4	26 1/2	18	9/16 x 1	4 x 10	10	6-1/4
42	31 1/4	25 3/4	18 3/4	22 1/2	16	9/16 x 1	4 x 10	9	6-1/4
43	27 1/2	23 3/4	16 3/4	20 1/2	12 1/2	9/16 x 1	4 x 10	8	6-1/4
44	26	21 3/4	14 3/4	18 1/2	10 1/2	9/16 x 1	4 x 10	7	6-1/4
45	43 3/4	36 3/4	26 3/4	33 3/4	20	9/16 x 1	5 x 12	13	8-1/2
46A	45 3/4	38 3/4	28 3/4	35 3/4	22	9/16 x 1	5 x 12	14	8-1/2
47A	54 1/4	48 3/4	30 3/4	44	24	3/4 x 1-1/2	8 x 18	15	10-1/8
48	38 1/4	34 3/4	24 3/4	31 3/4	20	9/16 x 1	5 x 12	12	8-1/2
49	37 1/4	31 3/4	22 3/4	28 3/4	20	9/16 x 1	4 x 10	11	7-1/2
50	44 3/4	38 3/4	28 3/4	35 3/4	22	9/16 x 1	5 x 12	14	8-1/2
51	48 3/4	40 3/4	28 3/4	37 3/4	22	9/16 x 1	5 x 12	14	8-1/2
52	58 1/4	50 3/4	34 3/4	46	28	3/4 x 1-1/2	8 x 18	17	10-7/8
53	41 1/4	36 3/4	22 3/4	33 3/4	20	9/16 x 1	5 x 12	11	8-1/2
54	41 1/4	25 3/4	24 3/4	22 3/4	20	9/16 x 1	5 x 12	12	8-1/2
60.4	24	16 3/4	16 3/4	14 3/4	12	13/32 Dia.	3 x 6	8	5-1/8
60.5	27	19 3/4	18 3/4	17 3/4	14	13/32 Dia.	3 x 6	9	5-1/8
61	39 3/4	25 3/4	24 3/4	22 3/4	20	9/16 x 1	5 x 12	12	8-1/2
63	33 3/4	21 3/4	20 3/4	18 3/4	18	9/16 x 1	4 x 10	10	6-1/4
64	43 3/4	25 3/4	26 3/4	22 3/4	20	9/16 x 1	5 x 12	13	8-1/2
65	33 3/4	28 3/4	18 3/4	25 1/2	16	9/16 x 1	4 x 10	9	6-1/4
66	46 1/4	25 3/4	26 3/4	22 3/4	20	9/16 x 1	5 x 12	13	8-1/2
69	31 1/4	18 3/4	18 3/4	15 1/2	16	9/16 x 1	4 x 10	9	6-1/4
71	60 1/2	35 3/4	31	31 1/4	24	3/4 x 1-1/2	8 x 18	15-1/8	10

Dimensions subject to change without notice.



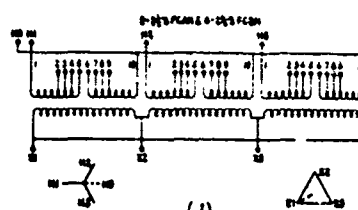
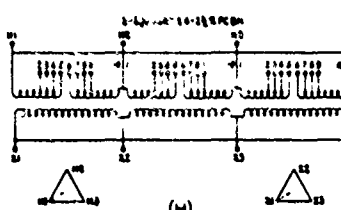
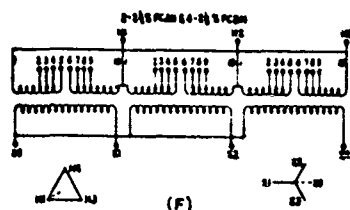
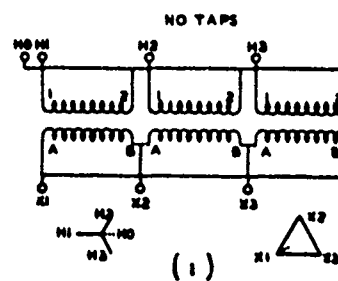
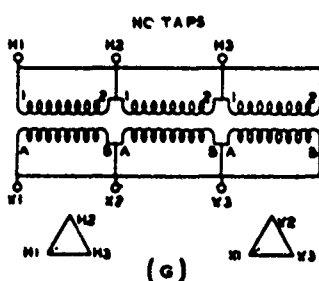
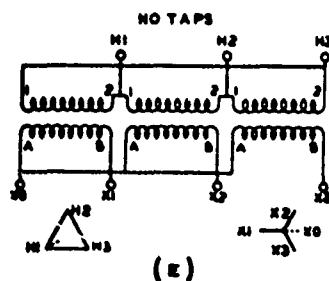
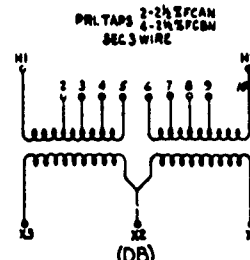
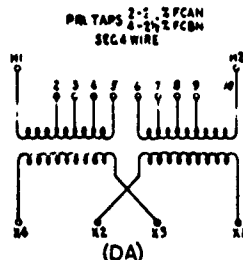
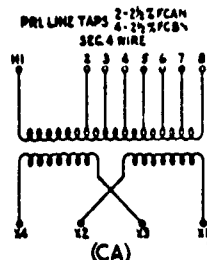
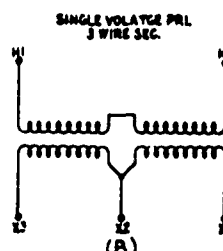
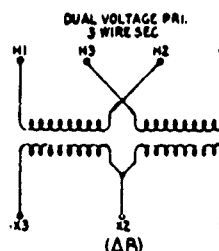
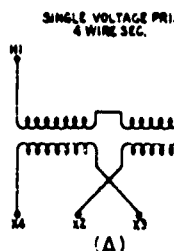
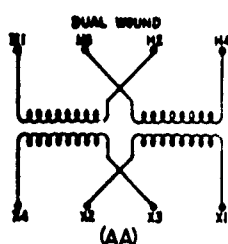
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CRITTENDEN TRANSFORMER

ATELEDYNE COMPANY

# WIRING DIAGRAMS



# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise

For Indoor Installation

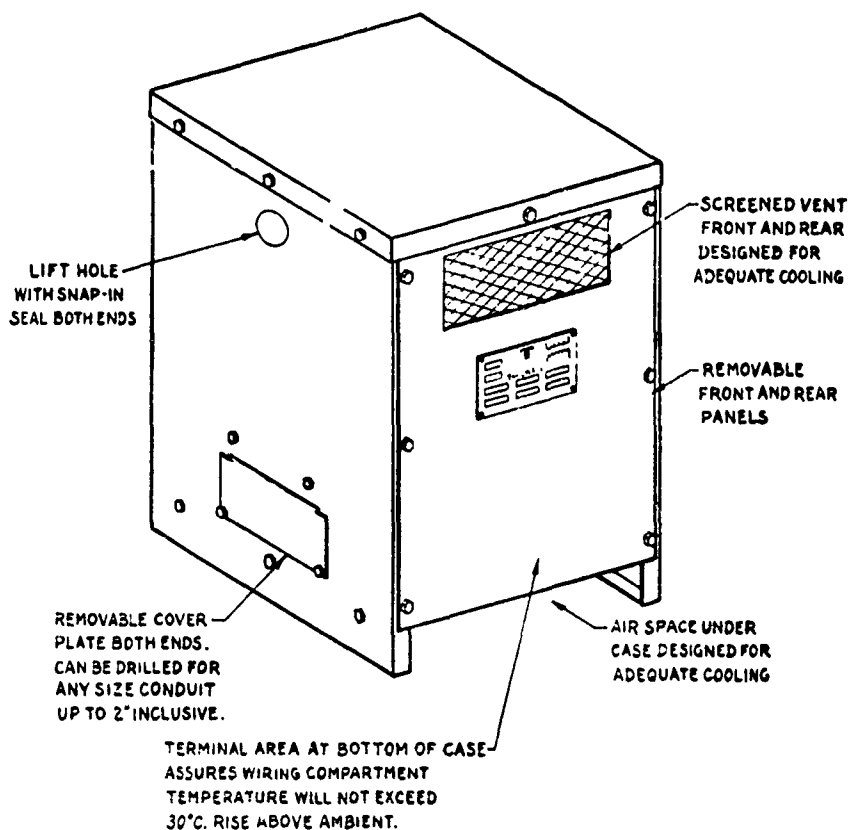
For Outdoor Installation Specify W/P Shields

Wall mounting brackets are available upon request for 15 thru 30 KVA at no additional charge. Wall brackets for 37½ thru 75 KVA are available at an additional cost of 5%.



## TYPICAL CASE CONSTRUCTION:

- #60,4 - 15 thru 30KVA, 1 phase, 600 V. Cl.
- # 15 thru 25KVA, 1 phase, 5 KV. Cl.
- #60,5 - 37½ KVA, 1 phase, 600 V. Cl.
- 30 & 37½ KVA, 1 phase, 5 KV. Cl.



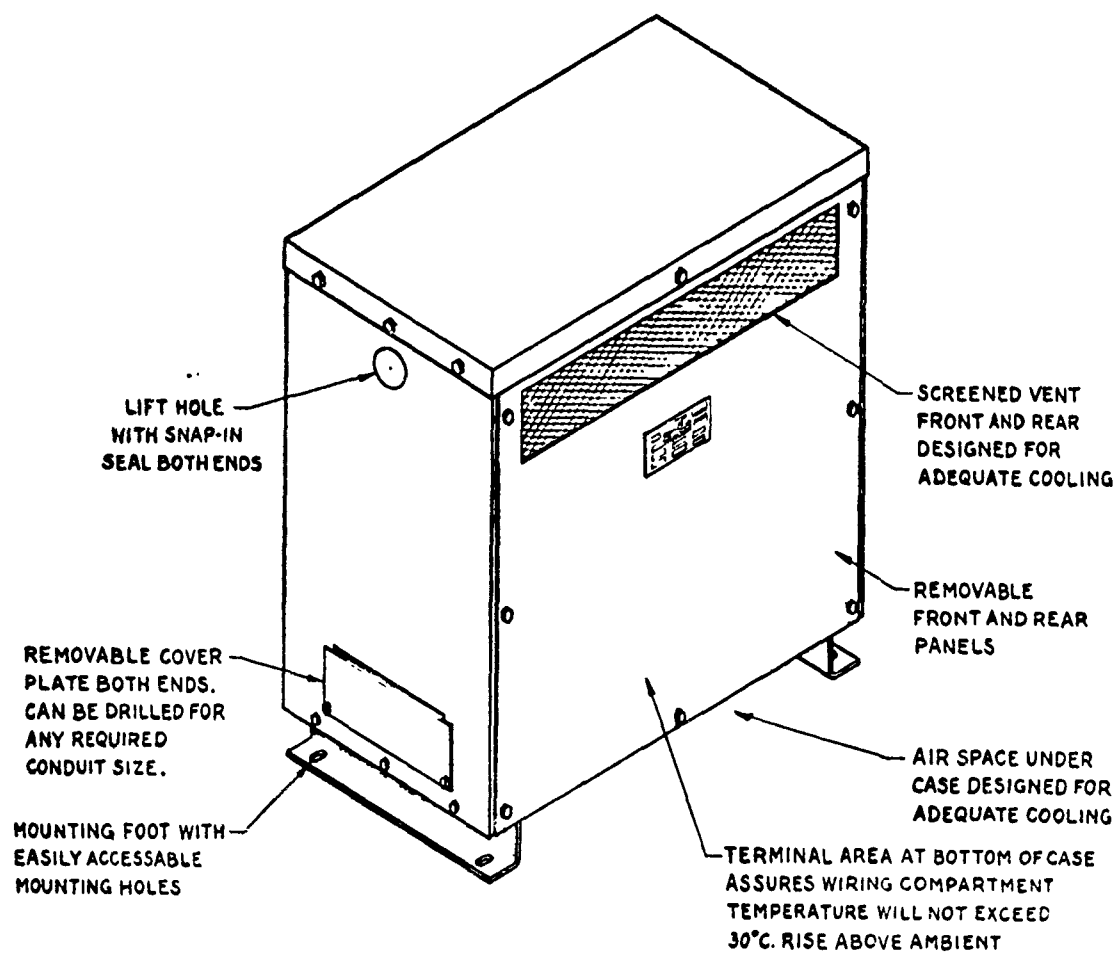


**CRITTENDEN TRANSFORMER**

**ATELEDYNE COMPANY**

### **For Indoor Installation**

**For Outdoor Installation specify w/P Shields**



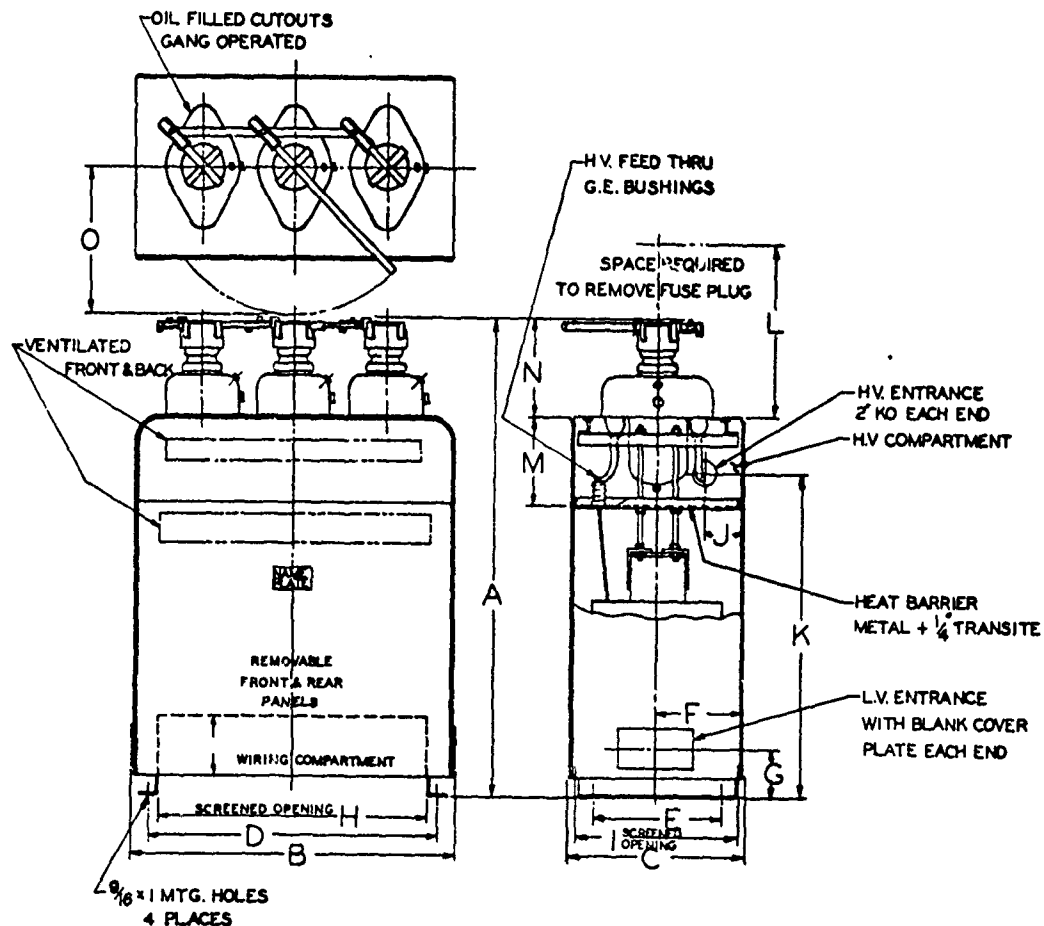
# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°C Rise

For Indoor Installation

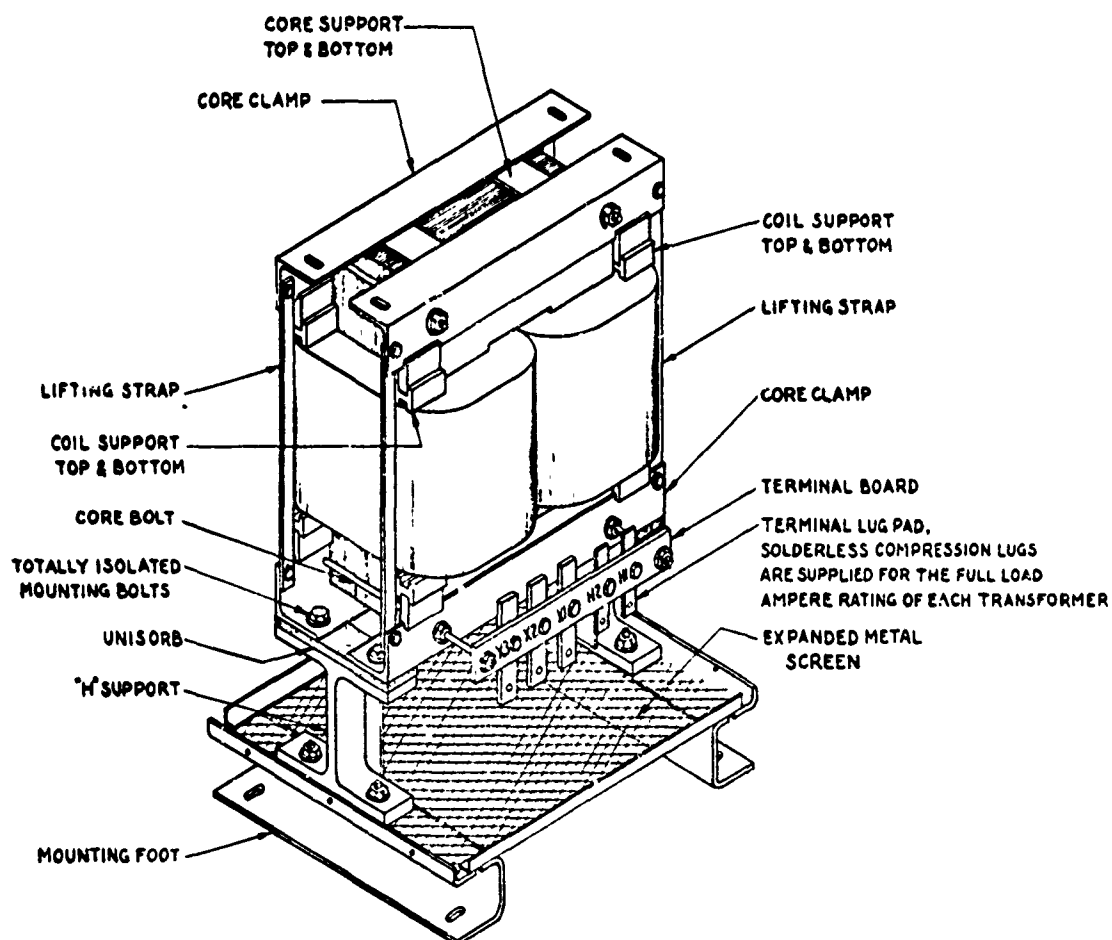
For Outdoor Installation Specify W/P Shields





CRITTENDEN TRANSFORMER

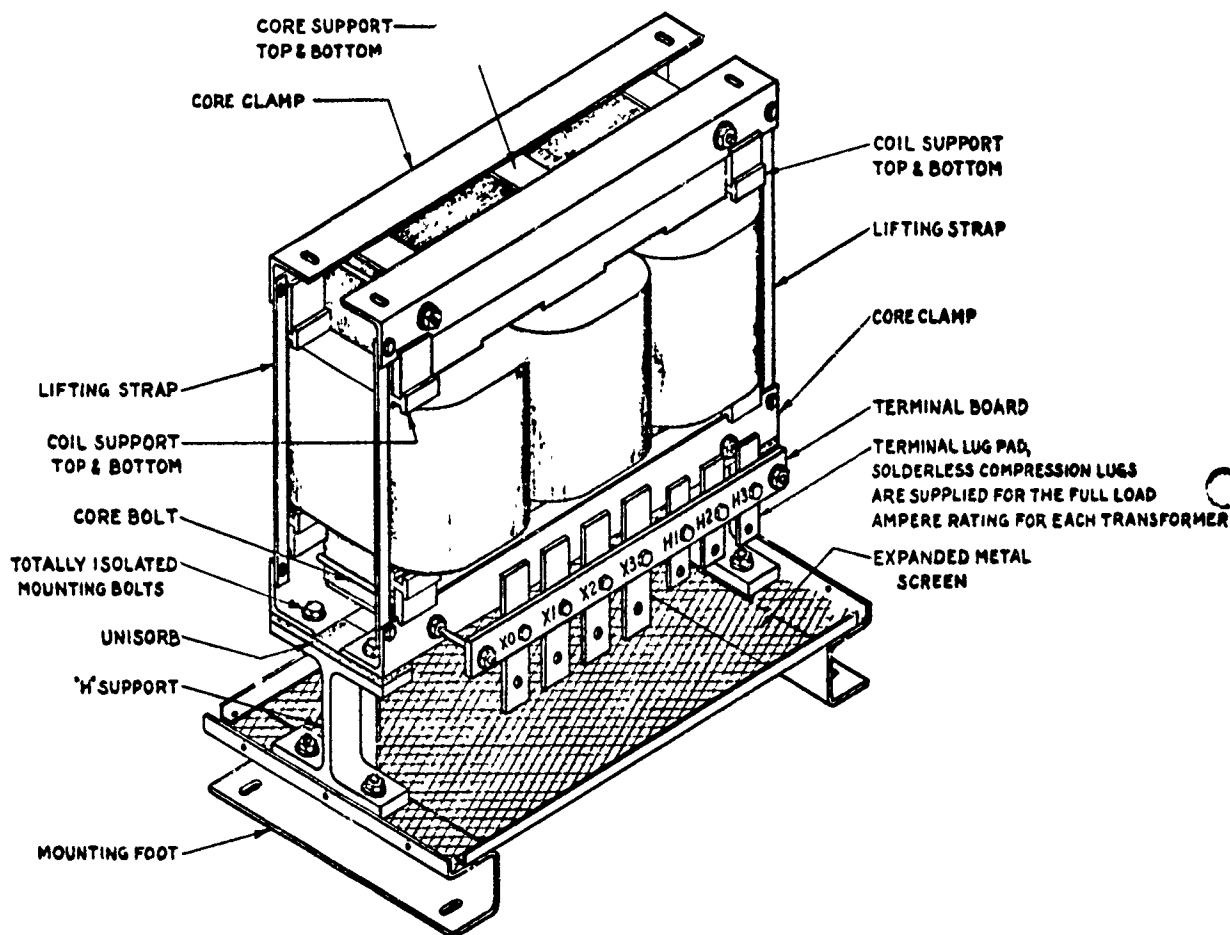
ATELEDYNE COMPANY



# DRY TYPE TRANSFORMERS

For Lighting & Power Service

Class H Insulated 150°c Rise



CRITTENDEN TRANSFORMER

A TELEDYNE COMPANY

11 November 1976

711 WEST KNOX STREET

GARDENA, CALIFORNIA 90248

(213) 327-0913 TELEX 67-7228

MAIL P O BOX 560 GARDENA, CA 90247

Jaros, Baum and Bolles  
1052 West 6th Street, Room 636  
Los Angeles, California 90017

Attention: Mr. Paul Katzaroff

Subject: 400 Hz Power Distribution at High Voltage

Dear Sir:

Teledyne Inet will be pleased to bid on any of the following equipment which may be a part of the U.S. Navy High Voltage 400 Hz Power Distribution System.

1. Motor generator sets, 60/400 Hz, which are synchronous and parallelable under load.
  - a. 312 KVA/250 KW with input voltage of 480 VAC, 60 Hz and output of 575 VAC, 400 Hz.
  - b. 624 KVA/500 KW with input voltage of 480 VAC, 60 Hz and output of 575 VAC, 400 Hz.
  - c. 312 KVA/250 KW with input voltage of up to 4160 VAC, 60 Hz and output voltage of up to 4160 VAC, 400 Hz.
2. Frequency changers, solid-state type, 60 to 400 Hz in power range from 75 KVA to 312 KVA and with input and output AC voltages in range from 120/208 VAC to 4160 VAC.
3. Power transformers, 3-phase, 400 Hz step up, 575/4160 VAC in KVA ratings from 125 to 1500 KVA.
4. Power transformers, shielded, low impedance types, 400 Hz step down, 4160 VAC to 120/208 VAC in power ranges from 30 KVA to 500 KVA.
5. Line drop compensators for passive reactive compensation in KVA ratings from 30 to 500 KVA.
6. Line voltage regulators, 3-phase, 400 Hz for active regulation of 400 Hz power lines in power ratings from 30 KVA to 500 KVA.

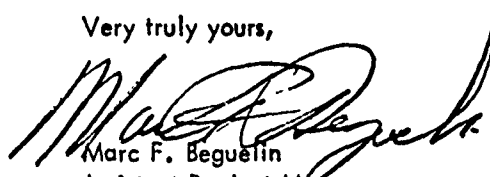
Jaros, Baum and Bolles  
Mr. Paul Katzaroff

11 November 1976  
Page two

7. Low voltage power lines and plugs, adapted to supply aircraft with 3-phase, 115/200 VAC, 400 Hz power.
8. Switchgear assemblies, 400 Hz to provide coordination between power generation and load equipment.
9. Control panel assemblies for control and monitor of 400 Hz power plant generation and load centers.

Enclosed herewith are literature and photographs illustrating the range of products available from Teledyne Inet.

Very truly yours,



Marc F. Beguelin  
Assistant Product Manager  
Power Conversion Equipment

MFB:jrm

Enclosures

... PIONEERS IN PRECISE POWER

## TECH/MEMO

### SOLID-STATE 400 HZ 17 KVA LINE VOLTAGE REGULATOR

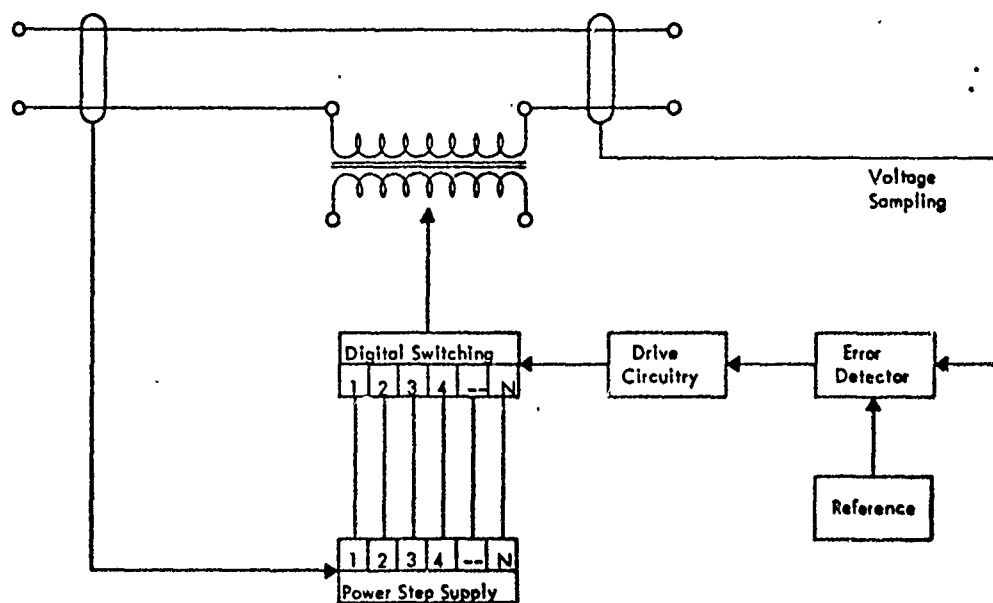
The Teledyne Inet 400 Hz 17 KVA Line Voltage Regulator is a solid-state device with important features and design parameters not available in previous magnetic-type units, including:

- Presents fixed impedance to power source with small effect on power source stability
- Fast response--40 millisecond full recovery
- Small size--16 x 20 x 8 inches
- Light weight--less than 95 pounds
- High efficiency--97% at full load
- No measurable input or output voltage distortion
- Short circuit proof with sufficient short circuit current to open a 150 Amp breaker
- Extremely low airborne and structure-borne noise
- Line drop compensation adjustable 0 to 7%
- Load rating--0 to 17 KVA, at any power factor
- Input power--115 VAC  $\pm 5\%$ , single-phase, 400 Hz
- Output power--115 VAC  $\pm 1/2\%$ , single-phase, 400 Hz
- Output current--0 to 150 Amps
- No phase shift with load; three units can be Y or  $\Delta$  connected for 150 Amps, three-phase, three- or four-wire

The excellent characteristics of the Teledyne Inet Line Voltage Regulator are achieved by a combination of solid-state analog voltage detection with solid-state digital switching. The output voltage is constantly maintained within  $\pm 1/2\%$  of nominal regardless of changes in the input voltage, load or temperature by the continuous addition of sufficient voltage to the incoming power, either in phase or  $180^\circ$  out of phase.

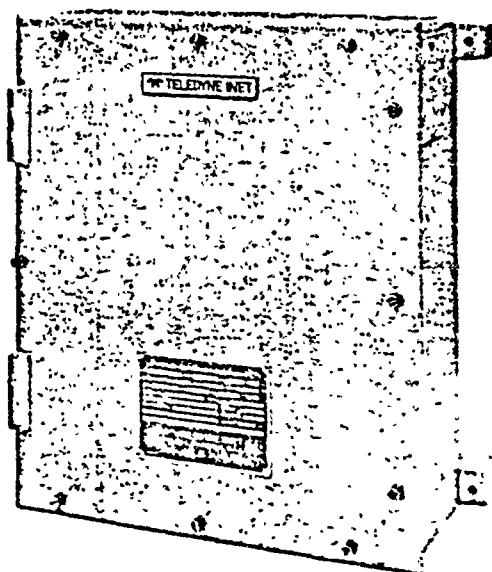
Buck or boost voltage is supplied by the digital switching section, or solid-state tap changer, in discrete  $1/4\%$  steps and at a switching rate of 400 cps. As a result, the output is a smooth sine wave regardless of changes in input voltage, output load or temperature.

Optionally, a solid-state Line Voltage Monitor can be incorporated into the Line Voltage Regulator to monitor output line voltage transients exceeding  $\pm 15\%$  of nominal voltage. When these voltage limits are exceeded for a period of 45 milliseconds minimum to 70 milliseconds maximum the monitor, using stored energy, trips a remote shunt trip breaker in the load line.

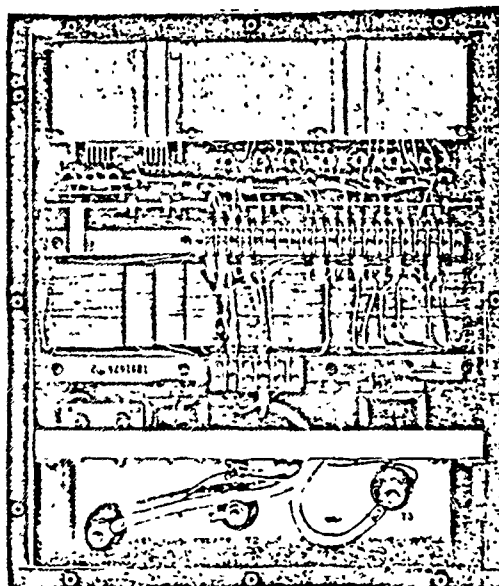


BASIC OPERATION BLOCK DIAGRAM  
Line Voltage Regulator

Figure 1



EXTERNAL VIEW



INSIDE VIEW

**400 HERTZ  
LINE DROP COMPENSATOR**

**TELEDYNE INET  
711 WEST KNOX STREET  
GARDENA, CALIFORNIA 90248  
Telephone: (213) 327-0913 - Telex: 67-7228**

1. GENERAL. A serious problem inherent in the use of 400 Hz Power Systems is voltage droop experienced as a result of load and/or distribution cabling between a 400 Hz 3-phase power source and the load. This droop may reach values as great as 20% of the nominal line voltage. Up to 90% of this loss may be caused by reactive drop in the cable, the balance being resistive (IR) cable loss. The voltage droop increases with load current for any fixed cable length and increases with cable length.

In an application where a branching distribution system is used, the problem of individual voltage compensation cannot be solved by the use of "voltage boost" techniques in the generator regulator, since these techniques depend on total load or average load sensing. The problem becomes particularly severe, and these methods of solution less satisfactory where multiple loads with widely varying individual load cable lengths are encountered.

An alternative solution to "voltage boost" in the regulator has been the attempted use of motor driven autotransformers in the load lines. The disadvantages of this approach are the slow response time, and the necessity for sensing and error voltage (motor drive) generation. The additional components and circuitry that become necessary lower the system reliability appreciably, as well as providing unsatisfactory speed of response to load changes.

As a solution to the problems of the above discussed techniques, Teledyne Inet perfected a passive compensation method that does not depend on load sensing and is accordingly free of the usual problems encountered in sensing and responding to load changes.

II. TELEDYNE INET PASSIVE COMPENSATION. The incorporation of a compensating device in each load line that eliminates reactive voltage drop rather than merely sensing and compensating for it greatly simplifies the problem of regulation at the load point. The compensation circuit corrects not only for the reactance in load lines but also of the generator which is the power source. This combined with the sensing circuit and control of the generator regulator provides simple and reliable control on voltage at the load.

III. NOMINAL SPECIFICATION FOR A PASSIVELY COMPENSATED 400 HERTZ SYSTEM.

A. Number of individual load lines: As many as required.

B. Load Point Regulation:  $\pm 3\%$  maximum regardless of multiple loads or load cable length.

C. Individual Load Cable Length: Up to 350 feet. On 115/200 VAC  
Up to 1200 feet on 575 VAC.

- D. Nominal load voltage = 120/208 VAC.
- E. Load Size: Up to 200 KW.
- F. Load Power Factor: 0.7 to unity.

#### IV. ADDITIONAL SYSTEM ASPECTS.

- A. Reliability. The reliability, defined as the mean-time-between-failure (MTBF) is in excess of 100,000 hours for the compensators. System reliability is limited by the MTBF of the motor generator or solid-state frequency converter.
- B. Maintainability. Depending on installation criteria, maintenance access to components of the compensator is through a hinged front panel. Due to the passive nature of the device, however, maintenance should rarely, if ever, be required.
- C. Input Voltage. In installations where a long central distribution bus is required, a step-down transformer can be incorporated in the compensator, allowing the use of a higher distribution voltage. This approach can save considerable installation cost because of the use of smaller wire and/or bus duct. Any input voltage from 120/208 to 575 or 1000 VAC can be accommodated, as can either three- or four-wire, wye or delta.

#### V. 400 HERTZ PASSIVE LINE DROP COMPENSATION

- A. SCOPE. This Specification describes a development of Teledyne Inet used to eliminate reactive line losses (line drop) encountered in the generation and distribution of 400 Hertz power. This system is applicable to installations having known fixed or incrementally variable load distribution cables, either single or multiple.
- B. SYSTEM DESCRIPTION. Normal load cable configuration used in the distribution of 400 Hertz power can create a line voltage drop of up to 10% of nominal voltage in worst case configurations with high current loads. In cases where multiple loads are connected to a single power source, particularly when the load is significantly different in the different load cables, an attempt to correct for line drop by sensing total load current, or averaging the load point voltages or currents, can result in severe over- and/or under-voltage conditions in one or more of the multiple load lines.

The passive line drop compensator, being connected in each load line and completely independent of all other load lines, compensates for losses only in its own load cables, eliminating any interaction problems with other loads operating from the same source.

The line drop compensator consists of various reactive elements interconnected in such a manner that when applied to a 400 Hertz power cable, the compensator effectively makes that cable appear to the power source as a negligible series resistance, rather than an appreciable reactive series load. The compensator may be placed at any point in the load cable that is convenient to the installation.

Once the LDC is adjusted for the cable length, no further attention is necessary to the solid-state unit. Short circuit protection is provided for the LDC.

In many applications the compensator may be designed to include a step-down transformer to change 575 or 1000 VAC to 120/208 VAC or any other combination of voltages.

- C. **TELEDYNE INET LINE DROP COMPENSATOR.** Compliance with the voltage regulation at the load points is demonstrated in calculations with various load combinations on the system. Calculations were made with the aid of a Hewlett Packard Model 9100B computer-calculator specially programmed to make the vector calculations of the specific system.

The line drop compensator has many advantages over the variable transformer or induction type regulator. The most important of these advantages are the unspecified electrical quality parameters which may render the system unusable using equipment presently specified.

1. **Transient Voltage Recovery** - The transient response of the line drop compensator, due to the nature of the circuit, will be less than one-half cycle, therefore the response of the system will be that of the generator-regulator (approximately 0.2 seconds no load to full load). The transient response of the other system will be 1 to 3 seconds or worse.
2. **Unbalanced Loads** - The line drop compensator minimizes the voltage unbalance due to load unbalance in the distribution system because each individual line is compensated separately, whereas the induction regulator corrects for the average drop of the three phases. Hence, under conditions where load current is not the same in the three lines, the line drop compensator will hold the specified voltage regulation and the induction regulator will not.
3. **Other mechanical advantages of the line drop compensator include:**

- a. Less space required (up to six line drop compensators assembled in one cabinet approximately 36" W x 24" D x 80" H).
- b. Only one input cable installation required from the generator.
- c. Only the 3-wire input and 3-wire output cables required. No control cables or remote sensing cables required.
- d. The line drop compensator is fully solid-state with no moving parts.

Figure 1 is a one-line diagram of the voltage regulation at the load points of a typical installation (substation #2 has the highest ratio, longest run to shortest run and will be used for this example). The computer analysis was made to determine what voltage would be present at load consoles under the most extreme conditions of load which could be connected to the distribution system, within the system rating. The computer program makes a complete calculation of all voltage drops, phase shifts, and the voltage boost response of the generator.

The following is a description of each of the component voltage vectors as shown in Figure 2:

- A. Generator. The generator vector will be assigned a voltage vector of 575 V at an angle of  $0^\circ$  ( $575/0^\circ$ ). This is the no load adjusted voltage.
- B. Regulator. The regulator vector will be assigned a voltage vector of 3.0 V at an angle of  $180^\circ$  ( $3/180^\circ$ ). This is the value of the voltage regulation no load to full load ( $\pm 0.5\%$ ) and the magnitude will be assumed to be linear with generator load.
- C. Boost Circuit. The boost circuit is adjustable from 0% to 5% and will be assigned a voltage vector of X volts at an angle of  $0^\circ$  ( $X/0^\circ$ ). This X vector is adjusted to the requirements of the distribution system and is not changed after initial adjustment. The magnitude of the vector also is linear with the generator load.
- D. Line Drop Compensator. The line drop compensator vector magnitude is adjustable in increments of 3.25 V to 6.5 V from 10 volts to 42 volts (at full load). The efficiency of the line drop compensator is assumed to be 95%. Its vector is capacitive in nature. The line drop compensator senses the branch current and so the voltage vector angle is affected by the

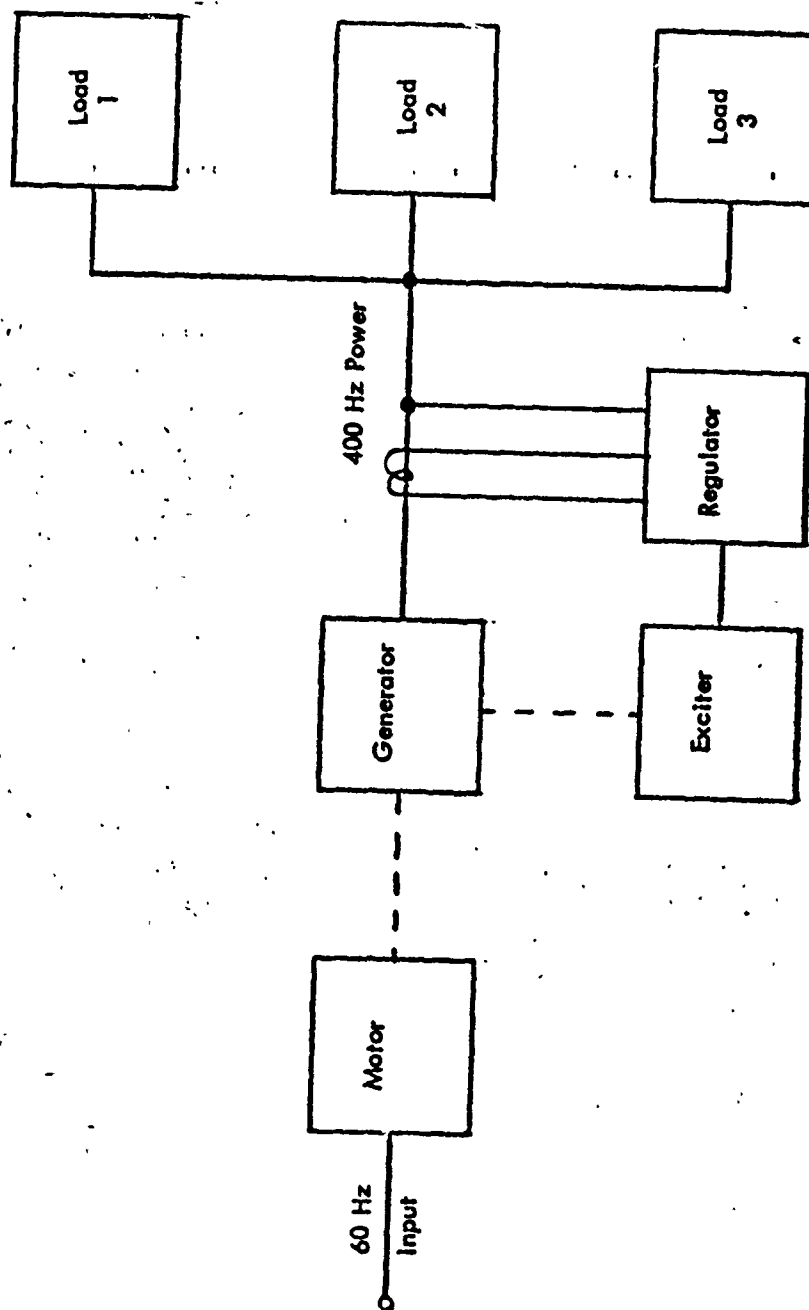
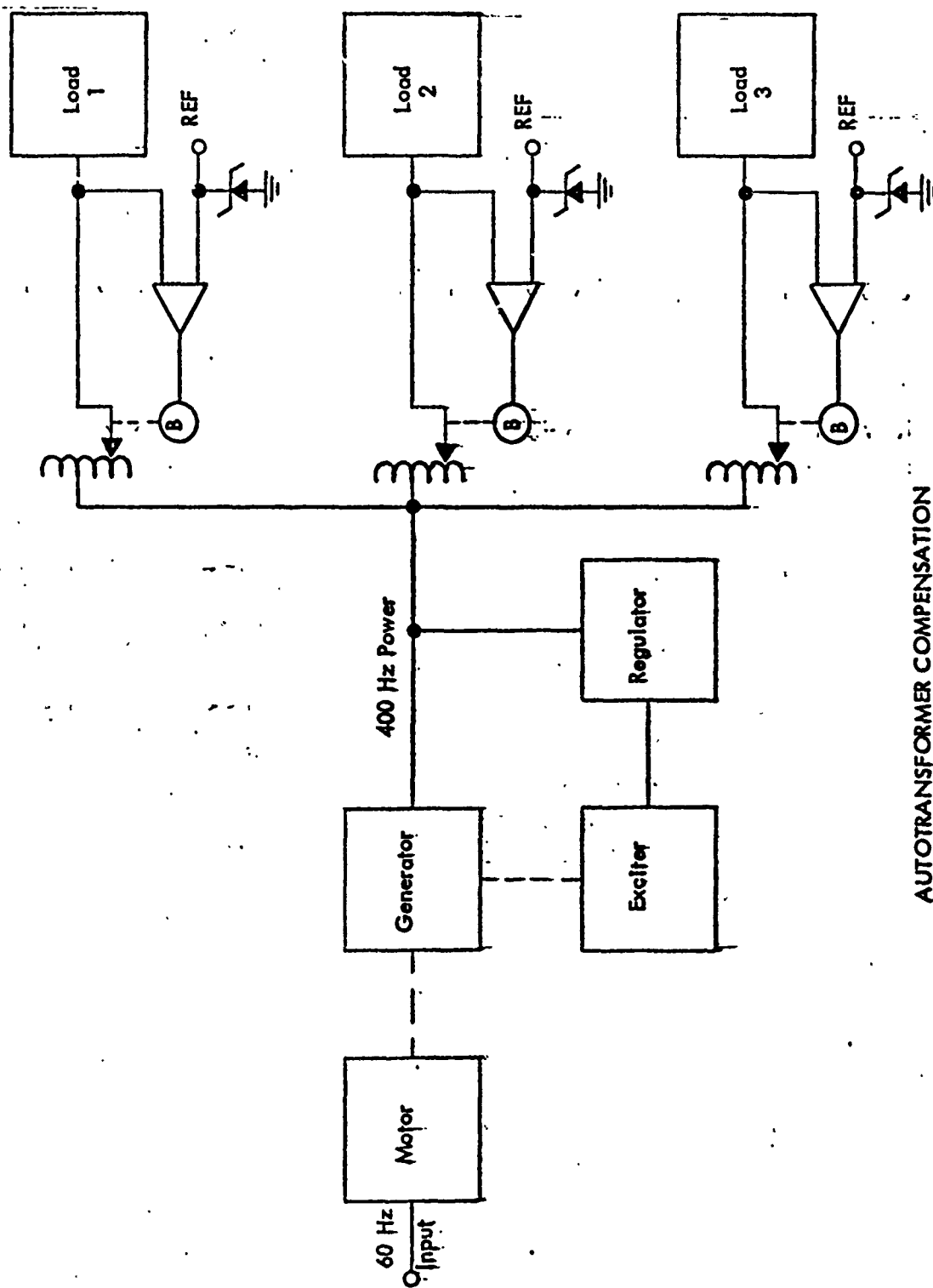
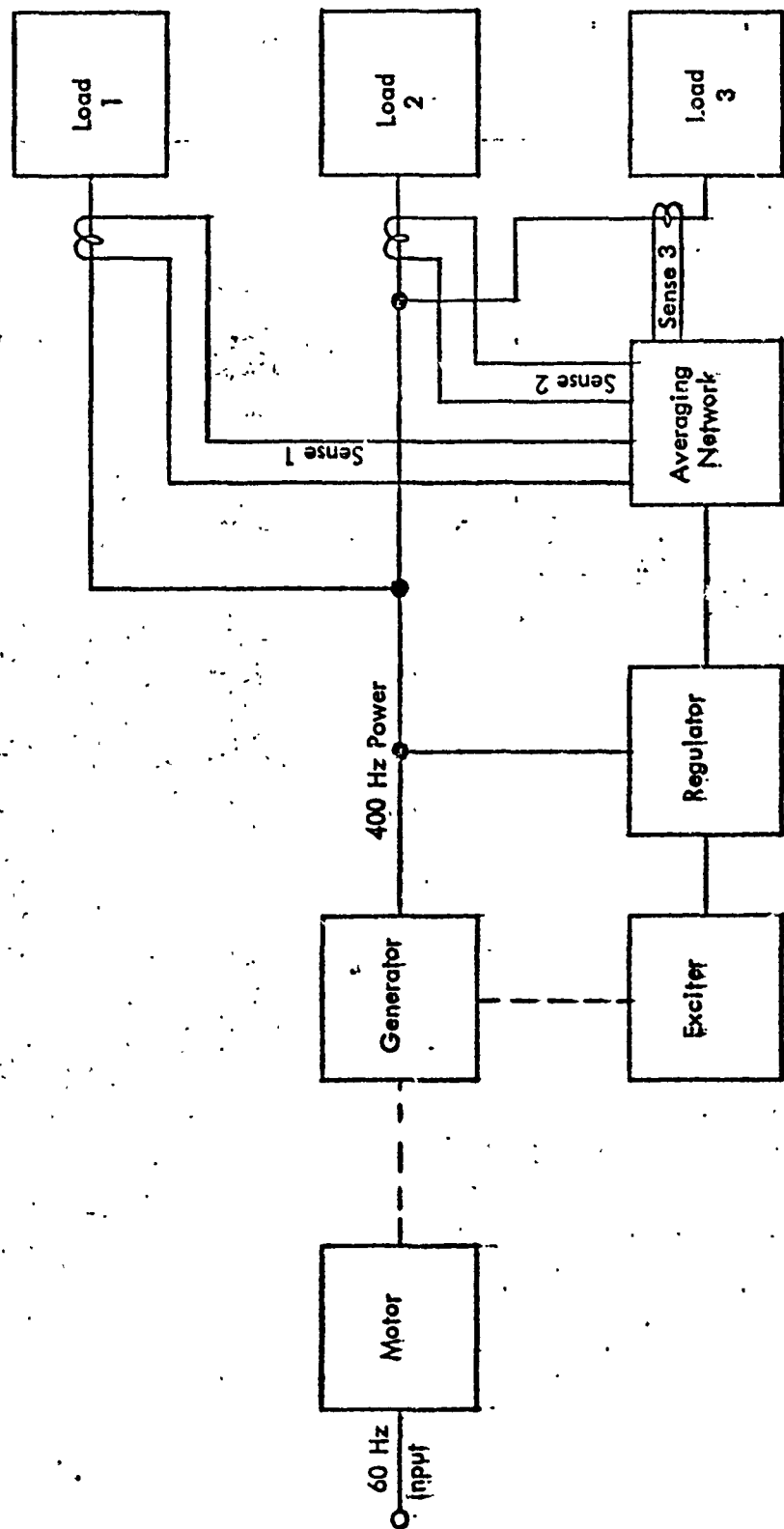


FIGURE 3 - LOCAL SENSE, TOTAL LOAD



**AUTOTRANSFORMER COMPENSATION  
WITH REMOTE VOLTAGE SENSING**

**FIGURE 5**



**FIGURE 4 - REMOTE SENSE, AVERAGING TECHNIQUE**

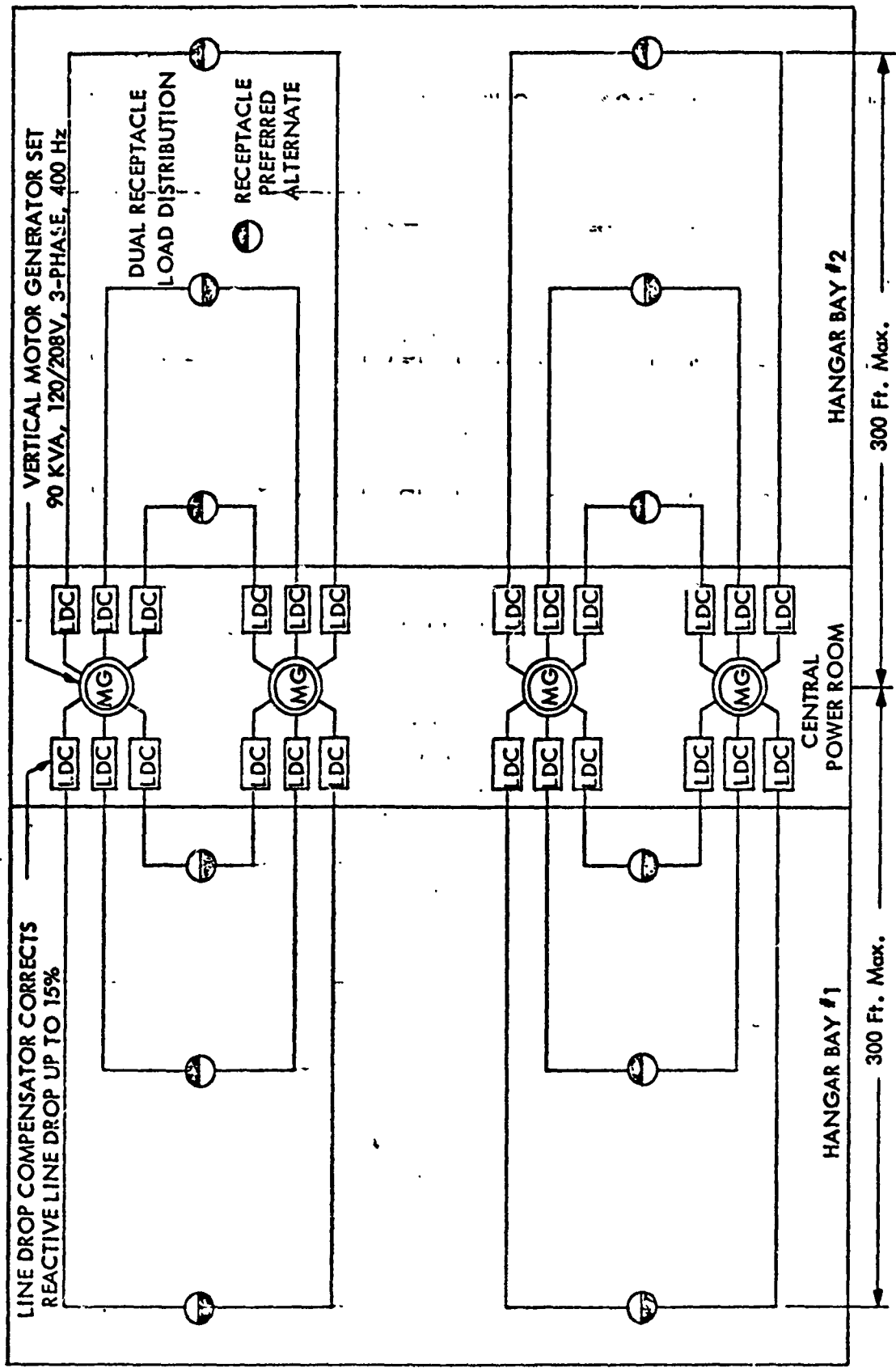
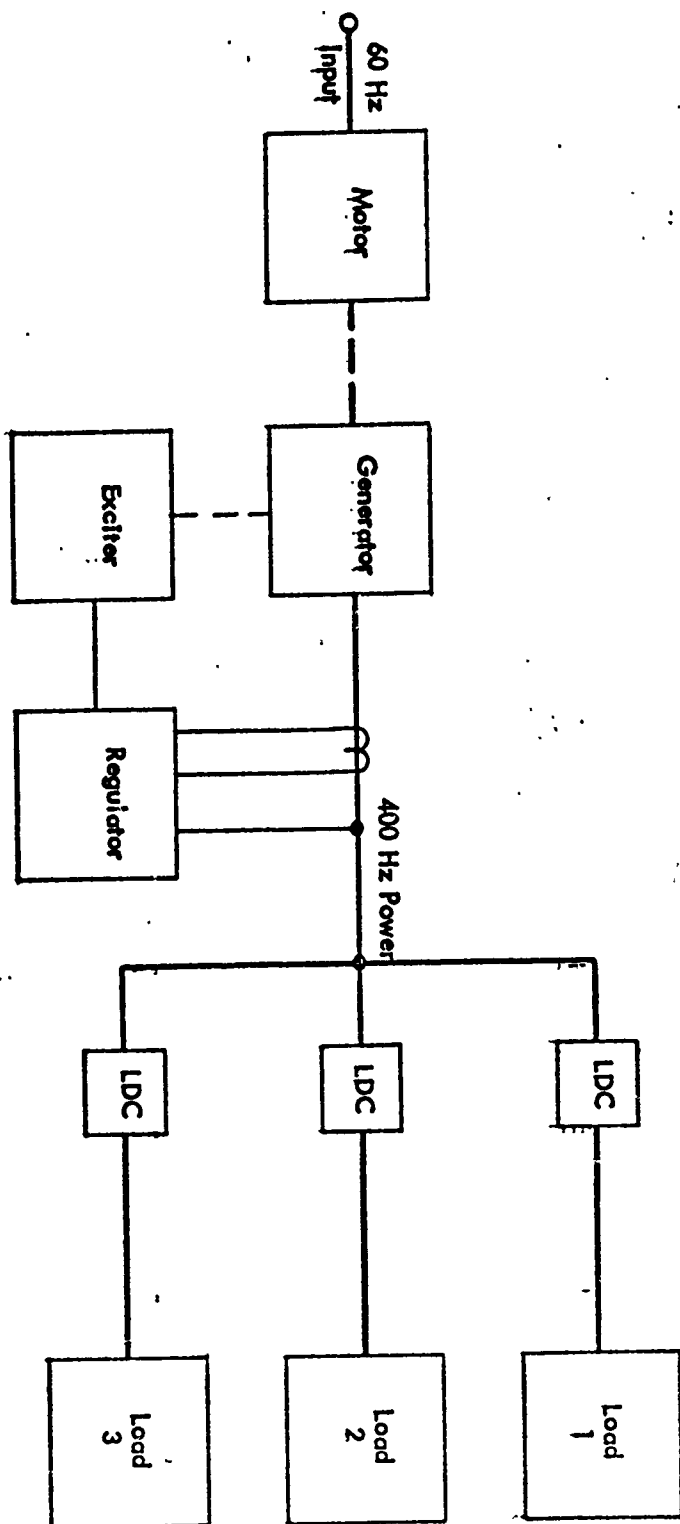


FIGURE 7

LINE MAINTENANCE BASES  
AIR CANADA, MONTRÉAL : TORONTO, VANCOUVER



**FIGURE 6 - PASSIVE LINE DROP COMPENSATION**

TABLE 1 LOAD CONDITIONS ON THE DISTRIBUTION SYSTEM

Load Condition	Gen Load KVA	BRANCH LOAD KVA PF				LOAD CONSOLE (KVA)											
		#1	#2	#3	#4	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	70	0	0	0	70/.8	0	0	0	0	0	0	0	0	0	0	0	70
3	70	0	70/.8	0	0	0	0	0	70	0	0	0	0	0	0	0	0
4	70	0	35/.8	0	35/.8	0	0	0	35	0	0	0	0	0	0	0	35
5	70	0	0	0	70/1.0	0	0	0	0	0	0	0	0	0	0	0	70
6	70	0	70/1.0	0	0	0	0	0	70	0	0	0	0	0	0	0	0
7	70	0	35/1.0	0	35/1.0	0	0	0	35	0	0	0	0	0	0	0	35
8	93.75	23.75/.85	35/0.8	15/0.95	30/0.9	5	10	8.75	15	5	5	5	0	10	0	10	20
9	93.75	0	10/0.9	50/0.8	33.75/.8	0	0	0	0	0	10	30	20	0	5	10	18.75

power factor of the load. The magnitude of the vector is linear with branch load. The line drop compensator vector will be assigned a voltage vector of  $Y / -92.86^\circ + \theta$ .  $Y$  is determined by the length of the distribution lines and branch load and  $\theta$  equals the arc COS  $\theta$  (COS  $\theta$  = Power Factor).

E. Distribution Cable. The distribution cable losses are largely reactive and can vary widely depending on the physical layout of the cable in conduit. A value of 10:1 reactive or .05 + i.5 ohms/100 ft is assumed for these calculations. Actual drops measured on similar distribution are much lower. This vector is assumed linear with distance and load and is affected by load power factor. The distribution cable vector will be assigned a voltage vector of  $Z / 95.5^\circ + \theta$ .  $Z$  is determined by the length of the distribution cable and branch load and  $\theta$  equals the arc COS  $\theta$  (COS  $\theta$  = Power Factor).

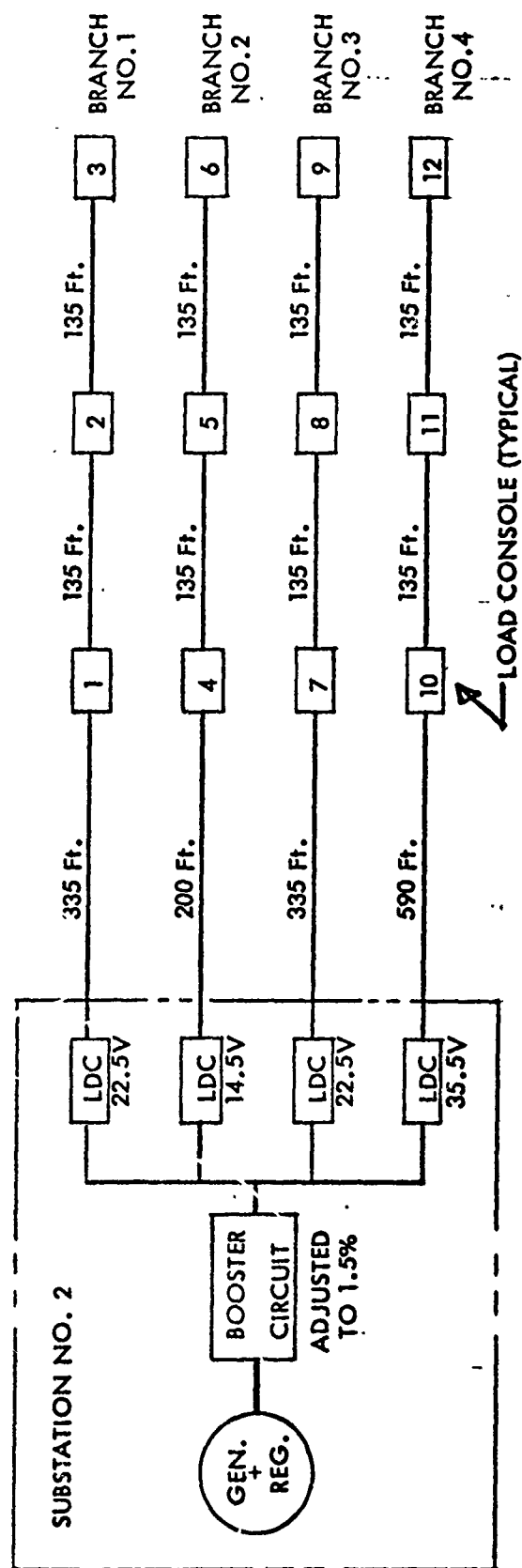
F. Transformer Regulation. The transformer impedance is stated as 2% maximum and is assumed linear with the load on the transformer. The regulation of the transformer at full load as reflected to the primary is 12 volts. It is assumed that this voltage is opposite to the main voltage, which is a worst case assumption. The voltage vector will be  $12 / 180^\circ$ .

The no load turns ratio (600:120) of the transformer can then be used to reduce the voltage at the load point to the use voltage. The specification for this voltage is  $115/200 \pm 2\%$  or the line-to-neutral voltage between 112.70 and 117.30 V.

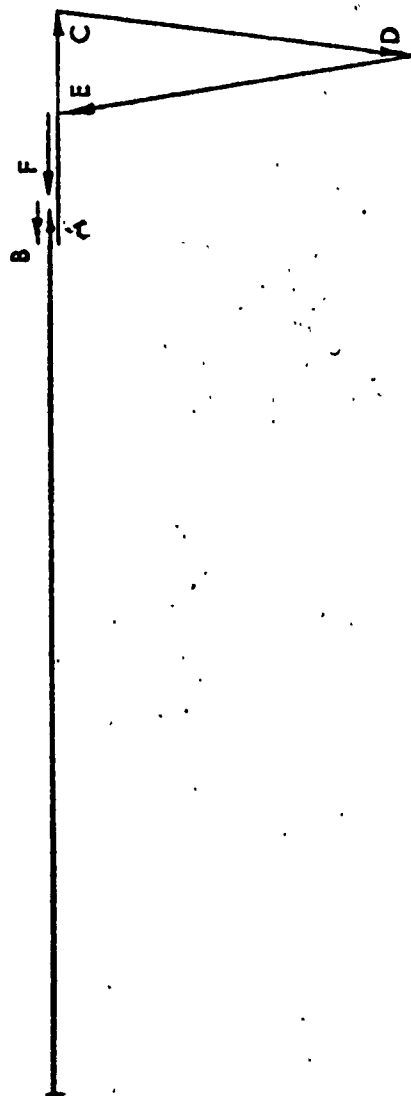
The goal of the compensation components of the system is to minimize the voltage variations with load at the various load points of the system. In Figure 2 the resultant vector is equal to the generator vector (A) and therefore is an ideal case with 0% regulation. Table 1 sets up several different load conditions on the distribution system (Ref. Figure 1). All sample loads are within the line drop compensator continuous rating and the total load on the motor generator does not exceed 125% of full rated load. All loads on one branch are of the same power factor to simplify the computer program. The line-to-neutral voltages recorded in Table 2 correspond to the load conditions of Table 1. All adjustments and distances for the sample calculations are indicated in Figure 1.

As can be observed from the data in Table 2, all load points stay well within the voltage regulation tolerances for any of the load conditions used.

Any typical load profile for the distribution system which can be forwarded to me, will be analyzed with the same program and returned for your information. Any number of loads within the unit ratings can be tolerated as shown in load conditions 8 and 9. The limit of the system is the generator KVA rating.



**FIGURE 1 - ONE-LINE DIAGRAM**



**FIGURE 2 - VECTOR DIAGRAM**  
**(FULL LOAD, ONE OUTPUT, UNITY PF)**

TABLE 2 LINE-TO-NEUTRAL VOLTAGES AT EACH LOAD CONSOLE

Load Condition	VOLTAGE AT LOAD CONSOLE (LIMITS: 112.70 TO 117.30)											
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
1	115.00	115.00	115.00	115.00	115.00	115.00	115.00	115.00	115.00	115.00	115.00	115.00
2	116.15	116.15	116.15	116.15	116.15	116.15	116.15	116.15	116.15	117.24	116.56	113.48
3	116.15	116.15	116.15	114.39	116.79	116.15	116.15	116.15	116.15	116.15	116.15	116.15
4	116.15	116.15	116.15	115.27	116.47	116.47	116.15	116.15	116.15	116.89	116.35	114.82
5	116.15	116.15	116.15	116.15	116.15	116.15	116.15	116.15	116.15	115.41	115.30	112.79
6	116.15	116.15	116.15	113.47	115.87	116.15	116.15	116.15	116.15	116.15	116.15	116.15
7	116.15	116.15	116.15	114.81	116.01	116.01	116.15	116.15	116.15	115.77	115.72	114.47
8	116.50	116.17	116.14	116.15	116.40	116.35	116.31	116.43	116.03	116.67	116.10	115.61
9	116.44	116.44	116.44	116.49	116.42	116.00	116.03	116.19	116.87	116.79	116.34	115.86